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of the
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BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

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Volume 15 Number 4

BULLETIN

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AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

APRIL 1931

STANDARDS IN CORRELATION[1]

J. E. EATON[2]
Los Angeles, California

ABSTRACT

The referring of sedimentary horizons to a standard column for a province commonly results in benefit to the geologist, for areal gradation and facies then become his allies when unravelling a whole. The use of local, duplicate names commonly hinders correlation, for when geological data form isolated groupings, areal gradation and facies become matters of bewilderment.

A standard column may be based on those types having priority which satisfy the requirements of utility. The fullest sections available may thereafter be used as controls to establish superimposition and ranges. California is cited as an example. Some regional correlations are given, and units available for use in the Miocene, Pliocene, and lower Pleistocene parts of a standard marine column are listed.

INTRODUCTION

We can imagine the confusion which would result if paleontologists had no standard time column; if, for example, the paleontologists in a province refused to recognize the term Miocene, called its horizon by different local names, and combined different parts of the Oligocene and Pliocene with it under various terms.

Confusion similar to that partly escaped in paleontology actually exists when we consider formations. It is true that a formation is ordinarily limited to a geologic province, whereas some forms dealt with in paleontology spread across continents and seas, but within a single marine province the analogy between the two is rather close.

[1]Manuscript received, January 3, 1931.

[2]Consulting geologist, 628 Petroleum Securities Building.

The thesis of the present paper is (1) that a marine formation is basically one unit throughout the range of deposition in one geologic province, (2) that the best interests of geology require that it be regarded and traced as such throughout the province.

UNITY

A formation is a unit deposited under one general control. If marine, it is commonly bounded at bottom and top by transgressive and regressive movements of the sea, regional changes in deposition, regional changes in fauna, or other recognizable natural limits. Where extended areally from its type, a formation commonly grades laterally to include different textures, bedding, thicknesses, and other aspects. Such areal gradation may be either progressive or irregular.

The unit as a whole may represent relatively fine or coarse sediments, but most marine units grade regionally from relatively coarse clastics near a strand to relatively fine muds in a general seaward direction, have intermediate textures, and contain many irregular, locally coarse or fine facies caused by eddying currents, by peninsulas or islands in the basin of deposition, or by other agencies.

A formation is commonly more or less of a lithologic unit at its type. It may retain some lithologic resemblance to the type areally, but because a type is merely a facies, lithology is a dangerous criterion; particularly because the sand facies of a unit may resemble the sand facies of an overlying or underlying unit more than it resembles the shale or limestone into which it may grade. The unity of a formation is, therefore, to be regarded as the sum or average of all of its facies, both areally and vertically, compared with the sum or average of all facies of other formations, and not as the unity existing in local facies. Thus, it is essential that a formation should be viewed regionally rather than through any local section or outcrop.

A common error is to forget that a formation is a regional unit which grades areally to present different aspects. We may know better, but the first time that we examine the type (a facies) of a formation, we probably subconsciously expect that equivalent sections which may be found a hundred miles away will be instantly recognizable by reason of a close resemblance to the type. Although the writer knows better than to expect this, he receives a preliminary shock, when, for example, he finds the type to be shale and the equivalent section to be sandstone.

GRADATION AND FACIES

Figure 1 contains the essence of the present paper. The upper part of this ideal illustration shows three formations based on local work. Each is one conformable, lithologic unit, and each has been given a local name.

The lower part of the figure illustrates relations uncovered by regional work. There is one *mappable* unit. The strandward edge of this unit bears little resemblance to the basinward edge, but the formation has unity. The three "formations" shown above are thus revealed to be local facies of the one mappable unit. Even these facies depend on isolation for existence. In the lower part of the figure they do not exist as unities, there being merely a progressive change which can not be divided areally at any point. There is one ever-changing whole.

If we could see all of a unit deposited in connected seas under one general control, we could nowhere divide it areally (Fig. 1).

We divide units areally only when we consider one part of them at a time, as in disconnected exposures. In the Cenozoic deposits of California it is chiefly the coarse, strandward edge of the original sheets

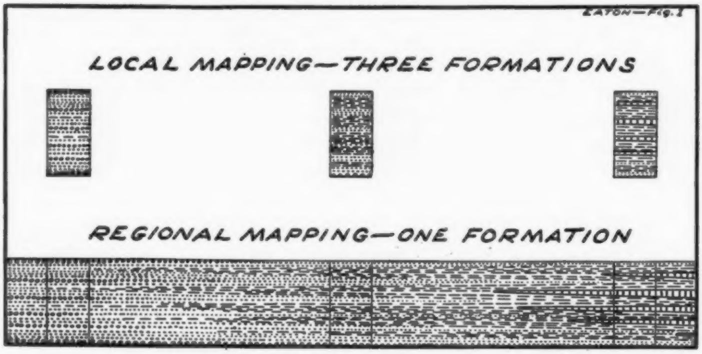

FIG. 1.—Diagram illustrating clarification which results from regional mapping during which gradation and facies are watched.

which is exposed, the finer facies being in large part under the sea. In the Paleozoic of the mid-continent provinces it is ordinarily the fine, basinward part which is exposed, the coarser edges having long since been eroded.

There are dominantly coarse and dominantly fine units in nearly all provinces, but qualitatively, a conglomeratic section along an ancient strand, and a limestone section a hundred miles away, can be the same formation. The limestone may be immediately overlain by almost identical limestone belonging to another unit, but if it was laid down under the same general control as the distant conglomerate, it has more unity with that conglomerate than with the almost identical limestone.

Here we approach the true definition of a formation. *A formation is a unit laid down under one areally and vertically modified general control.* Theoretically, any unit may be a formation. Practically, we must commonly restrict the term formation to a mappable unit, which means that we must at present rely chiefly on that unity which is traceable by means of transgressive, regressive, and faunal controls.

Divisions smaller than a mappable unit are known as zones. Two or more mappable units combined are termed a group. As a rule, a zone is the smallest regional division of the paleontologist; a formation, the smallest regional division of the field geologist; a group, the smallest regional division of the casual worker.

OBSTACLES

One of the important purposes of field mapping is correlation. Correlation ordinarily involves the establishing of a datum point or succession, followed by the areal and vertical extension of this by evidence and reasonable inference until it interlocks with other successions and datum points. Descriptive geology is thus merely a tool for creative geology—it is a poor, incomplete thing by itself, unworthy to be considered as an end.

Disconnected exposures.—An obstacle to correlation is the lack of connected exposures,—for example, in regions where two valleys or basins originally covered by one sea are now separated by mountains from which sediments have been eroded, or where such valleys or basins originally formed arms of the same sea but the point of coalescence is now hidden by alluvium or by an ocean.

If the disconnected areas were originally under one regional control, we need not recognize such obstacles as being more than hazards which make the game exciting, and add zest to humdrum work. He who has not discovered that the facies in one valley is equivalent to the somewhat different facies in a distant valley, or that the cool-water fauna of this open strand may be correlated with the warm-water fauna of that shallow, land-locked bay, has yet to taste the true satisfactions of geology.

When stepping from one disconnected area to another, the chief aid of the field geologist is commonly paleontology. However, he can almost double his resources if he will make gradation and facies his allies instead of his enemies. To do this he should consider the regional control—the causes, directions, and rapidity of gradation. If he could evaluate these factors correctly, he could predict precisely the sediments to be found in that other area beyond the mountain range. This is an ideal to be striven for, though never attained. But if he can not be ideally accurate, the geologist can at least learn to be accurate enough for most purposes of correlation. During his first few years of mapping in a province he will probably be lost when going from exposure to exposure, and must frequently submit faunas to paleontologists to discover where he is. When he can map a disconnected basin, submit faunas for comparison, and not have to revise his mapping, he has learned to use gradation and facies. At this stage he will probably stop using local names, and will carry standard units throughout the province.

Mistakes in correlation.—Mistakes will occasionally be made when correlating with a standard column. Such mistakes are the less serious of two evils. Confusion resulting from errors in correlation is temporary and comparatively easily remedied; that resulting from duplicate local names is more or less permanent and difficult to remedy.

When a geologist makes known a correlation with a standard column, he automatically places this correlation on record as being an opinion. It is accepted with suspicion by competent workers. Subsequent investigators will check his work, and if they find it to be in error will dispute his correlation and will correct the record. The confusion resulting from mistakes in correlation with a standard is therefore temporary and subject to correction.

On the contrary, numerous local names given to the same formation, or to parts of several formations in combination, may permanently confuse the record. The theory that local names are temporary does not work out in practice. They are printed in scientific publications of permanent record, are quoted by other workers in other publications, and creep into text-books. They are thus placed in the memory of hundreds of readers and students. Each name is a hundred-headed hydra which must be overcome before simplification of the record can be made effective. As a result, there are soon perhaps fifty confusing local terms in a province for ten regional units, and a simple stratigraphic column—easily deciphered by a systematic use of standards—becomes a complicated puzzle.

The writer does not deny the occasional propriety of local names, for these must sometimes be given in reconnaissance work, and in situations in which reasonable evidence for correlation is not available. He is calling attention to the feature that the whole, and not the part, is the goal of geology; that duplication results in complication; and that standards must be established if the relative is to be measured.

CONSTRUCTING A STANDARD COLUMN

The construction of a standard column will ordinarily involve three steps: (1) selection of unit types, (2) placing units consecutively in control (best) sections in order to check superimposition and ranges, and (3) regional mapping to ascertain regional relations. It may be advisable, however, partly to reverse the order of procedure given.

SELECTION OF UNIT TYPES

The major factors determining types for standard units are priority and utility. Theoretically, only utility should be considered, the formations preferably being named from control sections. This ideal is seldom attained. Practically, by the time a standard column is ready to be established most of its units will have been given mediocre local type names, some of which have become so well known that to substitute more useful type names from better sections is difficult. Also, prior names not only pay honor to pioneers, but priority is the simplest and most automatic way of settling conflicting claims.

We may include most of the benefits and avoid most of the weaknesses of the two factors by a legitimate compromise: a standard column may give preference to type names having priority, provided such type names satisfy certain basic requirements of utility.

A type name having priority may be required to satisfy the following points of utility or as many of these as are available in the province, before it is placed in a standard.

1. It should be marine if a marine horizon is available. (In California, this bars such non-marine types as Paso Robles, Tulare, and Kern River from use in a standard.)

2. It should not be an isolated fragment. That is, it should be in contact with the next overlying or underlying formation, or be extensible areally to some locality where such overlying or underlying contact can be ascertained. (In California, this bars such disputed fragments as the Santa Barbara and San Diego, whose types comprise a few feet of completely isolated beds.)

3. It should represent one regionally mappable unit, either by original definition, or by being restricted or expanded to one unit prior to use in a standard. (In Figures 3 and 4, the Santa Margarita is an original unit, the Saugus, Pico, and Etchegoin have each been restricted to one unit, and the [lower] San Pedro has been expanded to embrace one full unit.)

4. It should yield faunas if such are available, either macro-faunas, micro-faunas, or both. (All single units shown in Figures 3 and 4 have adequate faunas, macro-faunas having been found most reliable in the coarser facies, and micro-faunas in the finer ones.)

Other requirements may be added for other provinces, those listed being deemed essential for California. When a type name is adopted for regional use, it is advisable to drop any facies termination such as "sand," "shale," or "lime."

SUPERIMPOSITION AND RANGES

Before final decision is made on scattered or fragmental unit types tentatively recognized as combining priority with utility, it is advisable to place their horizons consecutively in the fullest and best exposed sections of the province in order to check superimposition and ranges. The best sections in a province are termed by the writer "control sections." These are not to be confused with the general control of deposition previously mentioned, being rather the best measure or standard for comparison available. Control sections enable us to determine what relation various scattered types bear to one another, and what expansion or restriction may be necessary in order to have each fragmental or weak type represent one natural unit in a standard column. Thus, though priority may force us to use types which are scattered, fragmental, and relatively poor, we can, and should, *assemble* these types on the basis of utility.

After selecting types entitled to precedence, placing these in control sections for superimposition and ranges, and restricting or expanding each to embrace one natural unit, we can accomplish regional mapping with some prospect of tracing gradation and facies.

CALIFORNIA AS AN ILLUSTRATION

An outline of the situation in California is given to illustrate the points advanced. This includes a historical resumé, some problems recognized by the writer and steps taken toward their solution, and

brief remarks on certain unit types and control sections available for use with a standard column.

HISTORICAL REVIEW

California came nearest to having a standard marine column in 1907, near the close of the "golden age" of California geology.

Following pioneer explorations by Blake near the middle of the nineteenth century, comparatively little work was accomplished on the marine Cenozoic of California for many years. In the last decade of the nineteenth century attention was turned to the immense Cenozoic marine successions of the Coast Ranges and the great central valley. During this decade and the years immediately following, work by Dall, Lawson, Hamlin, Fairbanks, and others on local columns and basins laid a foundation for more detailed investigations to follow.

The first decade of the twentieth century was noteworthy by reason of considerable mapping of the marine Cenozoic by F. M. Anderson, basic invertebrate determinations by Smith, and vertebrate work by Merriam. This was climaxed by the superb regional mapping and induction of Arnold, accomplished in collaboration with Eldridge, Johnson, and Robert Anderson. Arnold and his associates mapped a large part of the marine Cenozoic deposits of California, most of which work is recorded in publications of the United States Geological Survey.

In 1907, Arnold[1] proposed a standard column for the marine Cenozoic of California. From the standpoint of information then available, the column was remarkably accurate. Subsequent work has shown the San Pedro, Merced, Purisima, and San Pablo, as used by Arnold, all to be overlapping groups in need of restriction, and the Temblor must be inserted between the Vaqueros and Monterey. But the standard column of 1907 was basically a workable one. Had it been followed, with necessary restrictions and additions from time to time, a vast amount of stratigraphic confusion might have been avoided.

Following Arnold's retirement from active field work in 1910, the policy of the United States Geological Survey in California underwent a more or less abrupt change. This was perhaps caused partly by the necessity of accomplishing investigations with insufficient funds and partly by the inability to replace its foremost western paleontologist, for the high caliber of field workers was maintained. Whatever the reason, the Survey practically abandoned regional correlation and the use of a standard,

[1]George H. Eldridge and Ralph Arnold, "The Santa Clara Valley, Puente Hills, and Los Angeles Oil Districts, California," *U. S. Geol. Survey Bull. 309* (1907), p. 143.

and began to coin several local names. Among the new names proposed were Salinas, Maricopa, Topanga, Pico, Saugus, and the Monterey "group."

The writer wishes to point out that none of the names mentioned (except Saugus) has accomplished any useful purpose which could not have been accomplished equally well by using standard terms, and that several of them have needlessly confused the California column. The ostensible reason for local names, safety in nomenclature, has not been attained. The type Maricopa is post-Temblor in age, yet a great Temblor succession farther west which contains no Maricopa,[1] and Temblor beds north[2] of the type, have had the term Maricopa applied to them. The local term Modelo has been applied so as to include the Temblor, and to exclude it, in the same Survey publication.[3]

Local terms can be used more erroneously in California than standard names, because standard units are based on general controls whose modifications are traceable for hundreds of miles,[4] whereas local divisions are based on transient facies which change areally without revealing adequate reasons.

SYSTEMATIC USE OF TYPE AND CONTROL SECTIONS

During the first years of his work in California, the writer mapped without the assistance of systematic methods, and as a result made almost no progress. At the end of this period the state seemed to be a collection of unrelated parts, each local area seeming to have little relation to any other, but rather seeming to be a separate, uncorrelatable outcrop. The writer realized that he must outline some systematic method of attack. He decided that the first step in constructing such a method should be the selection of control sections for the establishing of superimposition, unit ranges, and adequate standards for comparison.

[1]See retractions in *U. S. Geol. Survey Prof. Paper 116*, p. 28, and in *Bull. 691-H*, p. 228. Mapping by the writer also shows these revisions to be necessary.

[2]Recent mapping and paleontologic work agrees in indicating that much of the succession commonly called Maricopa in northwestern Kern County is of Temblor, not Maricopa, age.

[3]*U. S. Geol. Survey Bull. 753*, plate 1. The Modelo, as thereon mapped, includes the Temblor horizon on the north, and excludes it on the south. This relation, suspected by the author of the bulletin at the time, has since been amply corroborated.

[4]For a contrary opinion, see G. D. Louderback, "The Monterey Series in California," *Calif. Univ. Dept. Geol.*, Vol. 7, No. 10 (1913). On evidence then available, Louderback concluded that the successions termed Monterey, Temblor, and Vaqueros were embraced in one natural unit which could not be regionally separated with accuracy because of areal gradation and facies.

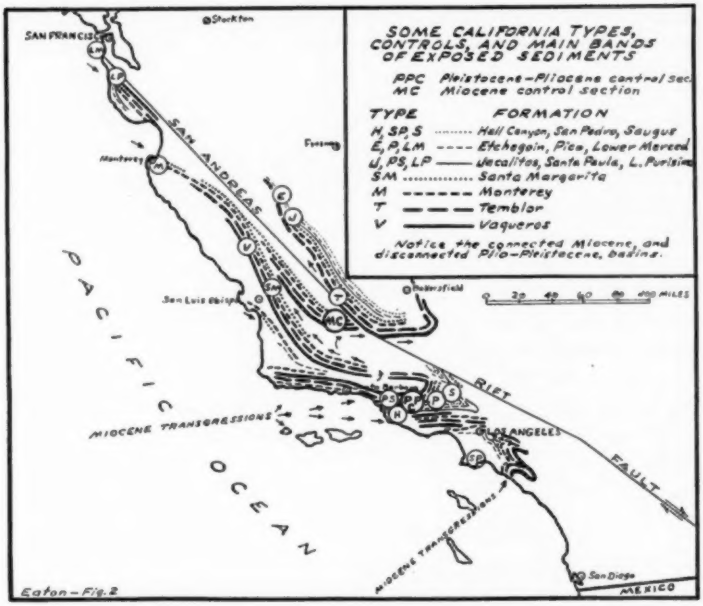

FIG. 2.—Miocene seas were widespread and lagoonal. Pliocene seas were restricted to narrower synclines. Shallow, brackish, lower Pleistocene arms record inception of Quaternary revolution.

The first control section was established 5 years prior to the present paper. It consisted of a 20,000-foot marine section, embracing approximately 15,500 feet of Pliocene and 4,500 feet of lower Pleistocene rocks. The whole was divisible into five units, four of which were distinct, and one indistinct.

The next step taken was to sample both this major control section and the different separated type sections foraminiferally from top to bottom, and give duplicate samples to three micropaleontologists. A succeeding step was to place the horizons of the different separated types in the control section, and carefully compare their ranges with the unit ranges therein by means of *Foraminifera*. At this point the writer made his first constructive discovery—that all of the widely separated types were either fragmental or were composed of groups, and that each must be restricted or expanded before accurate regional correlations could be made.

Following these preparations, the writer accomplished extensive regional mapping, extending the control section outward. As he proceeded, he found that most of the local facies which had puzzled him for years fell naturally into one or another of the units recognized in the control section. Areal gradation occurred, but the units retained their identity. Shale graded to sandstone, and sandstone to conglomerate, but it was a mappable gradation. Formation contacts could be determined regionally, and they revealed unconformities previously overlooked in local mapping. In mapping some isolated strandward fragments or overturned strata, field methods failed. In nearly all such difficulties the micropaleontologists completed the record by making use of the samples which had been furnished them from the type and control sections.

Two years after establishing this first control section, the writer selected his second, a 12,000-foot section of Miocene, in large part fossiliferous, and with all four of the standard Miocene units sharply defined. Figure 2 outlines the type and control sections referred to, and some main bands of exposed Miocene, Pliocene, and lower Pleistocene sediments.

Such success as the writer has met in correlation he lays primarily to a continual, combined use of type and control sections, to a persistent comparison of the one with the other, and to regional mapping during which gradation and facies were closely watched.

SOME CALIFORNIA FORMATIONS AND GROUPS

Figure 3 is a correlation chart for a part of the California marine column, presented to illustrate the possibilities for simplification in a province. It is based primarily on 10 years of field work by the writer, most of which has been accomplished in close coöperation with paleontology, particularly with the kindly aid of several micropaleontologists.[1]

The chart lists only a few of many conflicting designations, the names selected being those which have been used in more than a strictly local sense. Successions which extend into two or more regionally mappable units have been labelled as groups. Single, mappable units which are available for use in a standard marine column for California are shown in heavy outline. All units as used have reference to types, but where

[1]The writer acknowledges special indebtedness to Paul P. Goudkoff, Wilbur D. Rankin, and Donald D. Hughes, with the notation that, inasmuch as he integrated the various data, these workers are not necessarily in accord with all of the correlations shown.

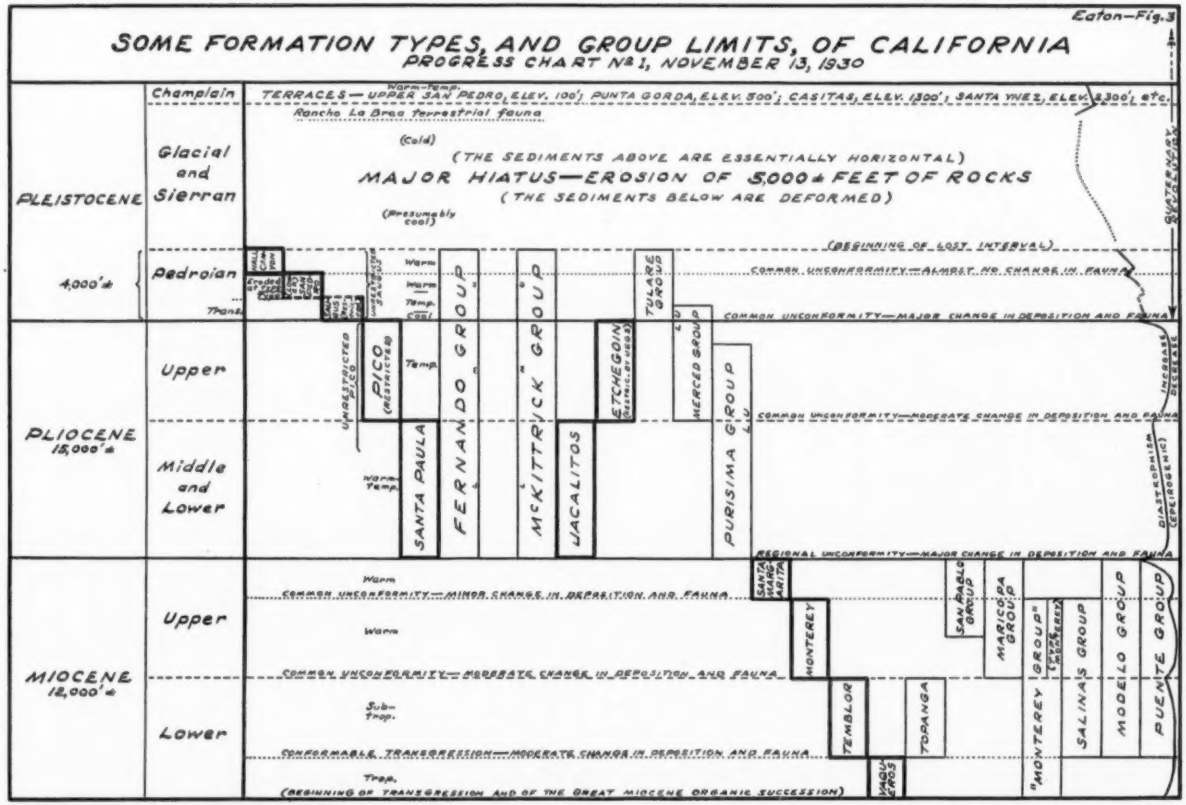

FIG. 3.—Epochs separated by solid, important regional divisions by broken, and less important regional divisions by dotted, lines. Single, mappable marine units available for use in a standard column are shown in heavy outline.

types are too fragmental, overgrown, or poorly exposed to represent exact ranges, the ranges are shown as they occur precisely marked in the great control sections.

The Monterey may be selected to illustrate confusion. The type (Blake, 1856) represents a unit which is regionally mappable in California. The Monterey unit involves a separate transgression and regression of the seas, and is widely unconformable with both the underlying Temblor and the overlying Santa Margarita units. According to the writer's work, type Monterey is equivalent to type lower Maricopa, upper type Salinas, middle type Modelo, middle type Puente, and upper Monterey "group." Also, upper type Monterey is equivalent to lower type San Pablo.

Such duplication is needless from the standpoint of the regional worker, because the Monterey is a mappable unit commonly distinct from the next underlying unit, the Temblor, and from the overlying Santa Margarita. The Monterey is not the only regional unit whose identity has been submerged in local names. The standard Temblor and Santa Margarita units also form confusing uppers, middles, and lowers in various erratic groupings.

UNITS AVAILABLE FOR A STANDARD MARINE COLUMN

Figure 4 lists those single, regional marine units in California of Miocene, Pliocene, and lower Pleistocene age which the writer has found to combine priority and utility, and which may, therefore, be considered available for use in a standard column.

By reason of the nature of a formation, two or more units representing different transgressions, hence somewhat widely separated by unconformity, should not be combined under one formation name. The writer has so far deemed it advisable to restrict an overgrown type which has priority to its most characteristic unit, rather than to discard it and propose a new name. In this connection, the Etchegoin, Pico, and Saugus, as shown, have been restricted to one characteristic unit. If just cause can be shown why the terms mentioned should not be restricted to a single unit, they will become unavailable for use in a standard column and the units should be renamed from the control (best) section.

Two of the terms listed in Figure 4 have been applied by the writer as a result of regional mapping. The term Hall Canyon was necessitated by reason of the delimiting of a lower Pleistocene unit which lies in the fuller sections unconformably between Arnold's lower and upper San Pedro units, and which had not been previously recognized in California, although its horizon had been included in groups or had been mistakenly

AGE	ON PRIORITY OF TYPE	ON MACROFAUNAL VALUE OF TYPE	ON MICROFAUNAL VALUE OF TYPE	AVERAGED
LOWER PLEISTOCENE	HALL CANYON	HALL CANYON	HALL CANYON	HALL CANYON
	SAN PEDRO L	SAN PEDRO L	---	SAN PEDRO L
	SAUGUS R	SAUGUS R	SAUGUS R	SAUGUS R
PLIOCENE	LOWER MERCED	ETCHEGOIN R	PICO R	(Conflict)
	LOWER PURISIMA	JACALITOS	SANTA PAULA	(Conflict)
MIOCENE	SANTA MARGARITA	SANTA MARGARITA	---	SANTA MARGARITA
	MONTEREY	MONTEREY	MONTEREY	MONTEREY
	TEMBLOR	TEMBLOR	TEMBLOR	TEMBLOR
	VAQUEROS	VAQUEROS	---	VAQUEROS

FIG. 4.—Alternative marine standards for California composed of single, mappable units. *L*, Arnold's lower series. *R*, restricted.

correlated with other units. The term Santa Paula was applied to a thick lower and middle Pliocene unit which lies with common unconformity between the underlying Santa Margarita and the overlying Pico-Etchegoin-lower Merced. This unit, previously undifferentiated in southern California, had been correlated in some parts of the area with the underlying Santa Margarita, and in other parts with the overlying Pico. The name Santa Paula was given to it in the control section, because, of its two correlatives, the lower Purisima is commonly loosely used to include younger rocks, and the Jacalitos can not very well be used in a standard sense until some settlement is made of the Purisima priority dispute. The writer has for five years called attention to the equivalency of the terms Santa Paula, lower Purisima, and Jacalitos, and will drop any two of them as soon as one is definitely accepted as a standard.

A few salient points regarding the units listed in Figure 4 are given in the following paragraphs. Gradation necessitates discussing averages recognizable with regional work, and it causes individual facies to vary somewhat from these averages for the whole.

LOWER PLEISTOCENE

Hall Canyon.—This is the highest marine lower Pleistocene unit in California. Its marine facies are as yet definitely known only from deep, western parts of the Ventura basin, but brackish and fresh-water facies are widespread in southern California and in the Great Valley. It is

composed chiefly of poorly bedded coarse clastics, pink to reddish weathering in non-marine areas. It is bounded at its top by the Sierran hiatus, and rests with almost regional unconformity on the (lower) San Pedro. The fauna is not very distinctive, and has been repeatedly confused with that of overlying terraces. The macro-faunal extinction is between 3 and 6 per cent.

(Lower) San Pedro.—The type represents a basal, fairly cool-water zone which is in contact with underlying sediments of Saugus age. Many hundred feet of higher sediments, eroded at the type, are present in the control section. These higher sediments show, as Arnold suspected, that the typical basal horizon grades rapidly upward to include warm-water faunas. The upper or warm-water faunas are difficult to differentiate from those of the overlying Hall Canyon formation, and even from those of late Pleistocene terraces. The marine facies of the San Pedro are composed chiefly of fairly well bedded and coarse white and gray clastics. There are some multi-colored beds in brackish-water areas. The macro-faunal extinction is between 3 and 8 per cent.

Saugus.—The term Saugus was applied, in *United States Geological Survey Bulletin 753*, to an undifferentiated succession of pre-San Pedro, San Pedro, and Hall Canyon age. A characteristic fauna was listed, however, from the basal, pre-San Pedro part on the west. The name Saugus has priority, regional significance, and utility only when restricted to the basal unit of pre-San Pedro age which carries the characteristic type fauna. The writer uses the term in this restricted sense. As restricted, the Saugus is dominantly a poorly bedded, somewhat coarse-grained clastic succession, which commonly contains, however, more clay than does the overlying San Pedro. The contact with the underlying Pico and equivalent successions is one of the sharpest and best in California,—the Pleistocene-Pliocene contact. The average macro-faunal extinction in the Saugus as a whole is about 9 per cent, but that in the extreme basal, cool-water zone may range as high as 15 per cent.

PLIOCENE

Lower Merced = Etchegoin = Pico.—These three equivalent terms designate the upper Pliocene transgressive sediments, predominantly poorly bedded, fine-grained, bluish and bluish gray clastics, with the lower part locally coarse-grained in strandward territory. The general unit is widely unconformable with overlying and underlying units, and even in those very deep basins where the contacts seem normal, the change in general control is marked. The lower Merced is used as

segregated by Dall, the Etchegoin as restricted to one unit by Arnold, and the Pico as restricted to one unit by Eaton. The fauna is exceedingly distinct from that of the overlying unit in unmixed collections. It is fairly distinct from that of the underlying unit, but has not been separated from this except by Arnold, Goudkoff, and a few other workers.

Lower Purisima = Jacalitos = Santa Paula.—These three equivalent terms designate the lower and middle Pliocene dominantly regressive sediments, these being in the main rather well bedded, coarse-grained, bluish and bluish gray clastics. Thin, fine-grained, brownish members are locally present, being most numerous in the lower half. The upper, coarser half is partly or wholly absent in many areas, being there represented by an unconformity which separates the unit from the upper Pliocene. Recent work indicates the unit to be regionally unconformable with the underlying Miocene. The fauna is distinct from that of the underlying unit. It is fairly distinct from that of the overlying unit, but has not been separated from this except by Arnold, Goudkoff, and a few others. The terms Jacalitos and Santa Paula represent original units. The term lower Purisima is used in the sense of the pre-Merced part of the type.

MIOCENE

Santa Margarita.—The Santa Margarita commonly exposes coarse, light-colored clastics, with a little interbedded limestone, siliceous shale, and volcanic ash. It apparently contains considerable diatomite in the area of certain former land-locked basins, but not all such sediment which has been termed Santa Margarita is certainly of that age. The unit yields a macro-faunal assemblage distinct from that of the overlying Pliocene, but somewhat closely related to that of the underlying Monterey.

Monterey.—The Monterey is dominantly extremely well bedded siliceous shale, diatomite, volcanic ash, and limestone, which grades areally to include sandstone and conglomerate on far-strandward edges. The unit was laid down in extensive, quiet, land-locked seas which at times became brackish. The Monterey contains micro-faunas of unsurpassed preservation at the type, and commonly elsewhere. Good macro-faunas are rare except in strandward facies such as at the type of the lower San Pablo group, and in the Santa Monica Mountains. The Monterey is widely unconformable with the overlying Santa Margarita and the underlying Temblor, but it has not been determined whether the seas completely withdrew from the very deepest channels. The un-

conformities, in general, are not angular, but rather represent quiet recessions and transgressions which cause large parts of the column to be absent.

Temblor.—The Temblor is dominantly somewhat well bedded clay shale and sandstone, the proportions varying areally. In the deep part of the basins the Temblor in many places contains some siliceous shale and limestone which may cause it to be confused with the Monterey in local work, but the two units are in general dissimilar. The range of the Temblor depositional unit coincides almost exactly with the range of the guide fossil *Turritella ocoyana*, there being, however, a thin basal transition zone in which this fossil overlaps slightly on Vaqueros guides, to which it is subject. The Temblor is widely unconformable with the overlying Monterey, but is commonly conformable with the underlying Vaqueros.

Vaqueros.—This is the basal, transgressive phase of the California Miocene. It is dominantly sub-massive sandstone, but locally contains considerable well bedded dark to black clay shale, and some limestone. In brackish areas the lower sandstones may be maroon, and the clay shale pink. Although commonly conformable with the overlying Temblor, the Vaqueros is regionally separable, particularly by reason of its exceedingly characteristic, almost tropical fauna. It is locally unconformable with the underlying Oligocene, but a common relation is conformable gradation upward from non-marine to marine deposition.

RECAPITULATION

A formation is a unit deposited under one areally and vertically modified general control. A formation is therefore a unit throughout the range of connected deposition, which is ordinarily limited to a province. The unity of a formation is determined by the average of all of its facies, compared with the average for other formations, rather than by the aspect of some local facies. For practical purposes, the term formation designates a single unit which is regionally mappable in the field. Smaller divisions are termed zones, and larger divisions, groups.

Because the goal of geology is a connected whole, it is helpful and advisable to trace formations regionally. If this is done, locally confusing aspects are shown to have orderly arrangement and causes, and gradation and facies become the allies of the geologist instead of his enemies.

It is commonly necessary to establish standards for comparison, if relations are to be ascertained. A standard column for a province

may be constructed from those types having priority which satisfy the requirements of utility. Where it is necessary to use widely separated, fragmental, or overlapping types, it is advisable to assemble these by placing their horizons consecutively in control sections to ascertain superimposition, ranges, and the amount of restriction or expansion which may be required.

A standard column is particularly needed in California, because certain of its control sections with a total thickness of approximately 45,000 feet of Cenozoic sediments constitute the most nearly complete known marine record for this era.

INDIVIDUALISM OF OROGENIES SUGGESTED BY EXPERIMENTAL DATA[1]

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ABSTRACT

A general discussion of the individualism of orogenic units as emphasized by experimental results is presented. The results of two experiments in which a very slight change in the artificial sediments used caused two very dissimilar miniature uplifts are given. The features of one of these uplifts were comparable with typical Foothills structure as found in Alberta. Additional criteria for distinguishing between individual over- and under-thrust faults are also submitted for consideration.

INTRODUCTION

Many scientists have questioned the use of laboratory experiments as an aid to the interpretation of geological structures. One of the objections most frequently presented is that there are too many unknown or variable factors involved in the building of an orogenic unit or a single structure to be duplicated in a laboratory. Scores of variable conditions which could cause many different individual structures or a group of structures can easily be enumerated. It is the writer's opinion that an unprejudiced experimenter realizes this to a much greater extent than the person who makes such objections merely on general principles. Just as variable forces, lateral and vertical variations of sediments, deeply buried or surficial rocks, et cetera, may cause a variety of structures in nature, so can a variation of comparable factors in the laboratory result in a variety of artificially produced structures. Although there probably is a limit to the number of factors which might be enumerated, the results may be infinite or beyond comprehension when combinations of these factors are considered. Probably no two structures in nature are exactly alike. Likewise it is essentially impossible to produce, by artificial methods, two structures exactly alike in all details, although the greatest care may be taken to have all factors precisely the same in

[1]Manuscript received, December 13, 1930. This is the last of a series of articles by the writer, presented in this *Bulletin*, which were based on laboratory experiments performed in the structural laboratories at the University of Chicago during 1926 and 1927.

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two experiments. However, two wholly different combinations of factors can result in two seemingly identical types of structure or structures. Although no two orogenic units are known to be alike in all respects, and no two individual structures in a specified orogenic unit are alike in all details, nevertheless, the terms, "Appalachian type" of folding, "Scottish Highland type" of faulting, and an "Osage type" of fold, are in use. Such classifications are justifiable, but should not be carried too far. Persian oil-field geologists who hope to explain structures in different parts of the earth by comparison with Persian structures must remember that the combination of factors or conditions which resulted in the Persian type of structure has probably never been operative anywhere else. It would be a coincidence to find the exact stratigraphic column deposited, and to find the same type and intensity of stresses operative during an equal length of time, in two widely separated areas.

The writer's object is to present and to discuss the results of two experiments in which only two factors or conditions were altered, and those only slightly, but which caused two decidedly different miniature uplifts.

DESCRIPTION OF APPARATUS

The pressure box used in the experiments described in this paper was 82 centimeters in width (normal to the direction of applied pressure), 48 centimeters in length (parallel with the direction of applied pressure), and 20 centimeters in depth (Fig. 1). Two large jack-screws were used

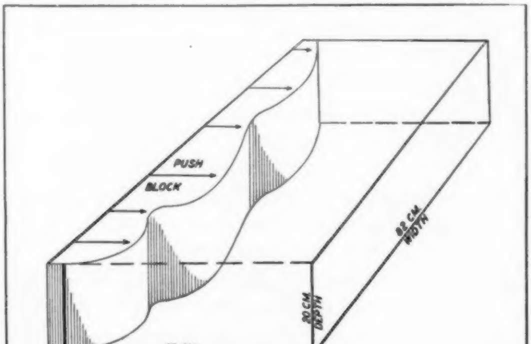

FIG. 1.—Illustrating shape of concrete push-block used and dimensions of pressure box.

to force a push-block of solid concrete against the artificial strata. The face of the push-block was not flat, but was molded with bulges and depressions in order to effect greater and less amounts of compression in the horizontal plane, as shown in Figure 1. It was thought that by using this push-block, "salients" and "recesses" might be developed in the resulting uplifts. A flexible rubber sheet was stretched across the side

TABLE I

EXPERIMENT 20 (APPARATUS C)

RECORD OF SEDIMENTS

Stratum	*Material*	*Amount in Kilograms*	*Weight in Kilograms*	*Thickness in Centimeters*
Overburden	Loose sand		27.00	6.65
Blotter	Blotting paper		....	....
Plaster	Plaster	1.20		
No. 4	Water	2.05	3.25	0.35
Sand	Sand	15.60		
No. 4	Cement	1.68		
	Water	3.71	20.99	2.60
Plaster	Plaster	1.10		
No. 3	Water	1.65	2.75	0.20
Sand	Sand	15.60		
No. 3	Cement	1.40		
	Water	3.71	20.71	2.60
Plaster	Plaster	1.10		
No. 2	Water	1.65	2.75	0.30
Sand	Sand	15.60		
No. 2	Cement	1.40		
	Water	3.71	20.71	2.40
Plaster	Plaster	1.10		
No. 1	Water	1.65	2.75	0.50
Sand	Sand	15.60		
No. 1	Cement	1.40		
	Water	3.71	20.71	2.30
Total plus overburden:			121.62	17.90
Total minus overburden:			94.62	11.25

Duration of deformation: 6 minutes (approximately)
Maximum height of uplift: 9.70 centimeters
Maximum width of uplift (including the push-block): 29 centimeters

of the box against which the curved face of the push-block was to be forced. This side was supported by a removable board while the sediments were being deposited. After the artificial strata had hardened sufficiently, the board was removed, and the concrete push-block was forced against the side covered by the rubber sheet.

NATURE OF SEDIMENTS

In the two experiments described (20 and 23), the greater part of the artificial sediments was essentially the same, except that in

TABLE II

EXPERIMENT 23 (APPARATUS C)

RECORD OF SEDIMENTS

Stratum	*Material*	*Amount in Kilograms*	*Weight in Kilograms*	*Thickness in Centimeters*
Overburden	Loose sand		40.50	10.00
Blotter	Blotting paper		....	....
Top plaster	Thin veneer only		....	0.10
Grease No. 4	Petrolatum Paraffine	0.50 0.20	0.70	0.30
Sand No. 4	Sand Cement Water	15.60 1.60 3.70	20.90	2.70
Grease No. 3	Same as grease No. 4		0.70	0.30
Sand No. 3	Same as sand No. 4		20.90	2.50
Grease No. 2	Same as grease No. 4		0.70	0.20
Sand No. 2	Same as sand No. 4		20.90	2.70
Grease No. 1	Same as grease No. 4		0.70	0.30
Sand No. 1	Same as sand No. 4		20.90	2.70
Total plus overburden:			126.90	21.80
Total minus overburden:			86.40	11.80

Duration of pressure: 7 minutes (approximately)
Maximum height of uplift: 7.80 centimeters
Maximum width of uplift (including the push-block): 32 centimeters

one of the experiments four layers of pure plaster of Paris were used, and in the other, four layers of grease or petrolatum were substituted, interbedded with thicker sand strata. A complete record of the artificial sediments used in both experiments is given in Tables I and II.

A comparison of these two tables shows that in both experiments the sand layers, which constituted almost 90 per cent of the total thickness, were of almost the same weight and thickness. The plaster of Paris layers were somewhat heavier, but were only slightly thicker than the grease layers. From the nature of the sediments it is obvious that those used in Experiment 20 were, as a unit, more rigid and competent than those used in Experiment 23. However, the overburden used in the latter was approximately 3.50 centimeters thicker and was proportionately heavier than in Experiment 20. A somewhat greater rigidity and competency were thus imparted to the underlying strata in Experiment 23. Briefly stated, one would not expect a radical difference in the nature of the resulting uplifts if the same amount and type of forces were applied against the sediments listed in the foregoing tables.

COMPARISON OF THE TWO STRUCTURES

Figures 2 and 3 are side or stereogram views of the two formations resulting from experiments after removal of the overburden. Because the views were not taken from exactly the same angle, and because the blotting paper had not been removed in Experiment 23 before the resulting formation was photographed, a detailed comparison can not be made. However, the fact is noteworthy that the uplift in Experiment 20 is 0.90 centimeters higher and 3.00 centimeters narrower than the structure produced in Experiment 23.[1] Figures 4 and 5 are vertical or top views of the two resulting uplifts after removal of overburden and blotting paper. These show clearly more and larger transverse tension fissures and also steeper dips produced in Experiment 20 (the experiment in which the plaster of Paris layers were used). The letters *A-B*, *A-C*, et cetera, indicate the lines along which six cross sections were cut through each of the models. The cross sections for Experiment 20 are illustrated in Figures 6, 7, 8, 9, 10, and 11, and the corresponding cross sections for Experiment 23 are shown in Figures 12, 13, 14, 15, 16, and 17. A comparison of each group and of the individual corresponding sections clearly shows that the same type of structure was not developed in the two experiments.

[1]See explanatory notes in Tables I and II.

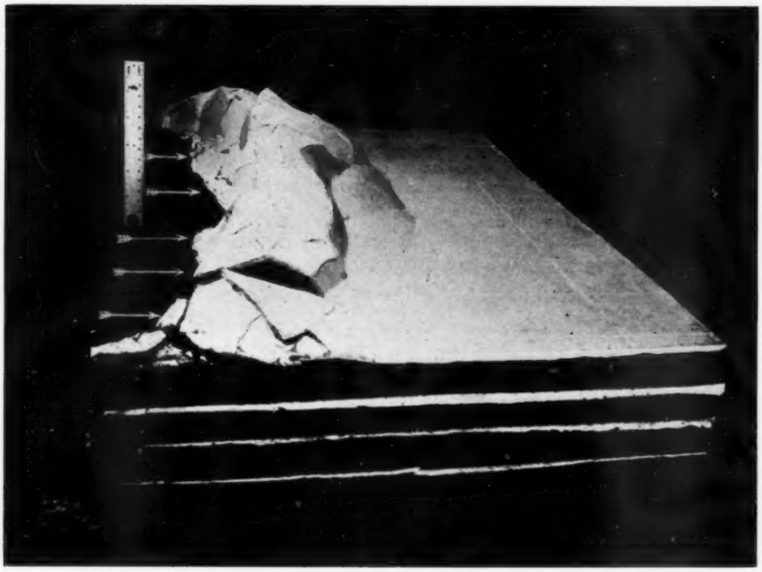

FIG. 2.—Oblique view of formation resulting from application of pressure in Experiment 20. Concrete push-block was forced against artificial sediments as indicated by arrows. Notice how uplift dies out toward observer. Scale at left represents 15.2 centimeters (6 inches).
Courtesy *Imperial Oil Review* (Toronto, July, 1929).

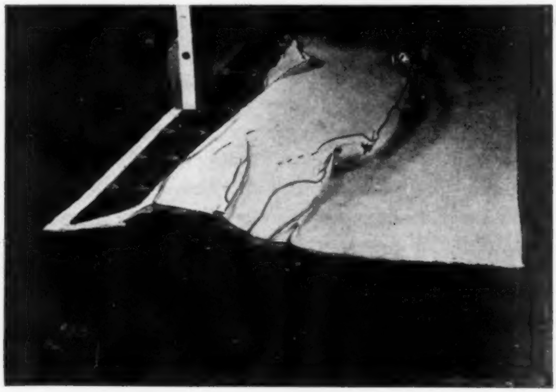

FIG. 3.—Oblique or side view of formation resulting from Experiment 23. Concrete push-block was forced against artificial sediments as indicated by arrows. Photograph was taken before removal of blotting paper. Scale at left represents 15.2 centimeters (6 inches).
Courtesy *Imperial Oil Review* (Toronto, July, 1929).

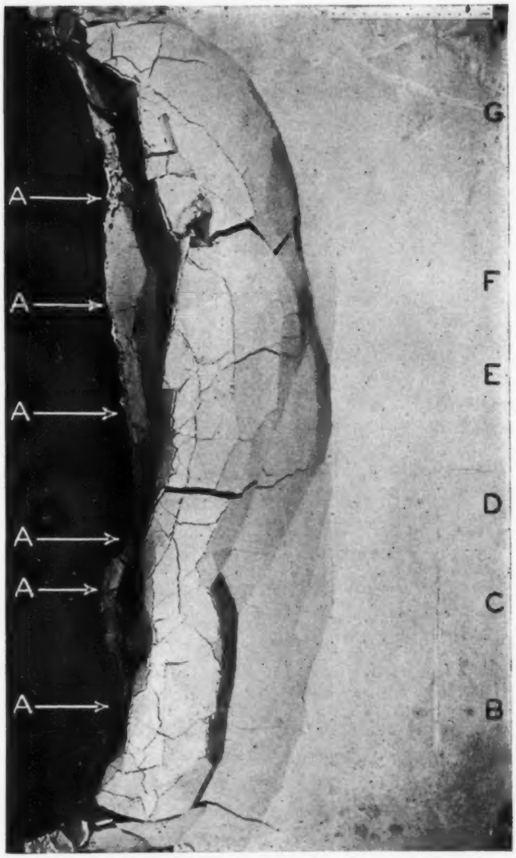

FIG. 4.—Vertical or top view of formation resulting from Experiment 20, illustrating nature of uplift and shape of push-block. Arrows indicate direction of applied pressure. Letters *A-B*, *A-C*, et cetera, indicate position of various sections cut through model which are illustrated in Figures 6-11. Scale in upper right corner represents 15.2 centimeters (6 inches).

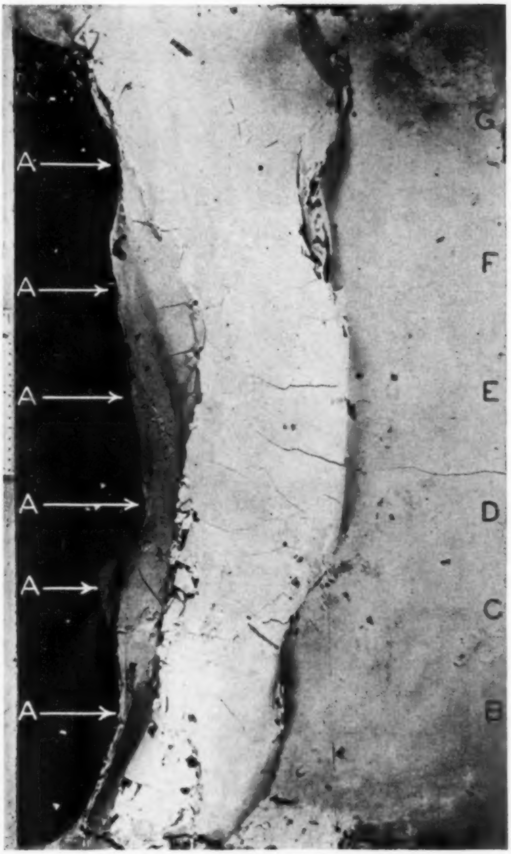

FIG. 5.—Vertical or top view of formation resulting from Experiment 23, illustrating nature of uplift and shape of push-block. Arrows indicate direction of applied pressure. Letters *A-B*, *A-C*, et cetera, indicate position of various sections cut through model which are illustrated in Figures 12-17. Scale at center of left border represents 15.2 centimeters (6 inches).

Figures 6, 7, 8, 9, 10, and 11 clearly show that underfolds were more prominent than overturned folds, and that overthrust faults are only slightly more numerous than underthrusts. In only two sections (*A-F* and *A-G* of Figs. 10 and 11) did the overthrust faults reach the surface. The plaster layers were broken or fractured extensively because of their brittleness. One would not expect the grease layers to react in the same manner.

A careful study of Figures 12, 13, 14, 15, 16, and 17 reveals that the uplift resulting from Experiment 23 shows a decided predominance of branching overthrust faults and that in each cross section at least one of these faults reached the surface. One underthrust fault is noticed in the top layer of cross section *A-D*; surficial underfolds are shown in only two other cross sections, *A-C* and *A-G* (Figs. 13, 14, and 17). The dark grease layers did not fracture as much as the plaster layers in Experiment 20. In general, the uplift is broader and less complicated than in the previous experiment. Because the overburden was slightly thicker in this experiment, it is very probable that more underfolding may have occurred in that part of the section. The writer has previously offered this explanation in regard to the seeming absence of underthrusting in experiments with excessive overburdens.[1]

COMPARISON OF CROSS SECTIONS IN SAME EXPERIMENT

EXPERIMENT 20 (COMPLEXITY)

Because of the nature of the push-block used, one would not expect the six cross sections of the same model to show exactly the same structure. A lateral variation of stresses should naturally result in a similar variation in structure. The change in nature of the structure from section to section in Experiment 20 is very great (Figs. 6, 7, 8, 9, 10, and 11). Space does not permit a discussion of the individual features, which are clearly shown in the illustrations. A comparison of the lower white bed in section *A-B* (Fig. 6) with that in section *A-C* (Fig. 7) is interesting. In the former there is one big overthrust fault near the push-block and a much smaller one approximately 16 centimeters toward the right. In section *A-C* there are two thrust faults of approximately equal displacement. One lies approximately 7, the other approximately 16 centimeters from the push-block. A variation in structure of this kind would not be difficult to trace in the field, but when the same bed is studied in the

[1]Theodore A. Link, "Relationship Between Over- and Under-Thrusting As Revealed by Experiments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 8 (August, 1928), pp. 847-48.

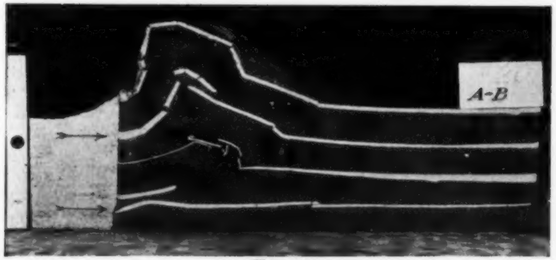

Fig. 6

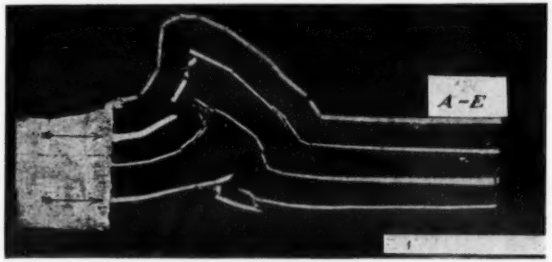

Fig. 9

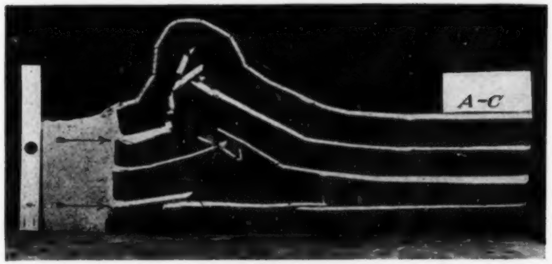

Fig. 7

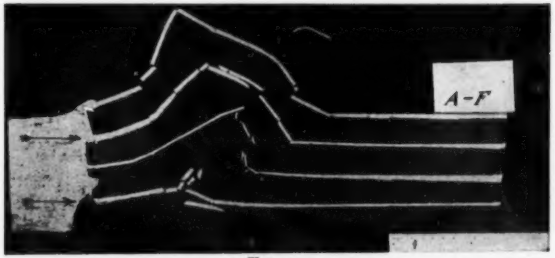

Fig. 10

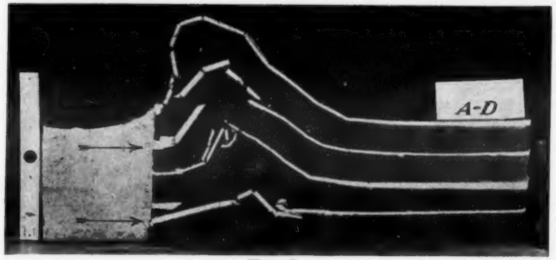

Fig. 8

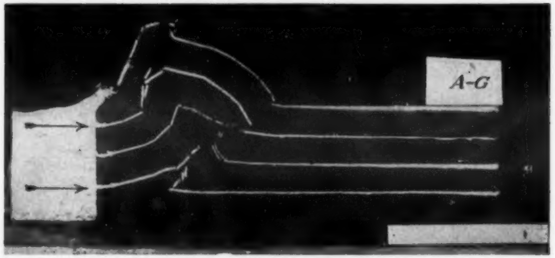

Fig. 11

Figs. 6-11.—Illustrating six cross sections cut through formation resulting from Experiment 20. For position, see Figure 4. White mass at left represents push-block; arrows, direction of applied pressure. Width of white mass graphically shows amount of compression or variable shortening effected at each section. Scale at left represents 15.2 centimeters (6 inches). These sections are to be compared with corresponding sections of formation resulting from Experiment 23 (Figs. 12-17). Courtesy *Imperial Oil Review* (Toronto, July, 1929).

corresponding sections of formation resulting from Experiment 23 (Figs. 12-17). Courtesy *Imperial Oil Review* (Toronto, July, 1929).

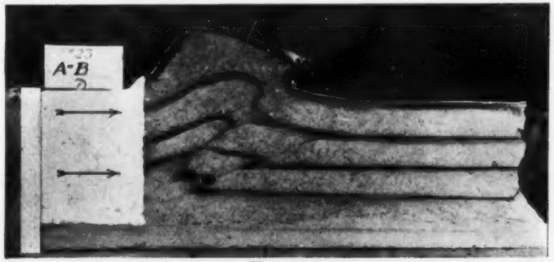

FIG. 12

FIG. 15

FIG. 13

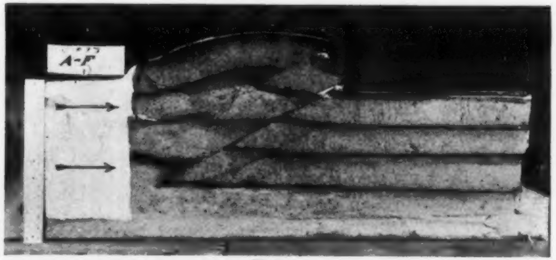

FIG. 16

FIG. 14

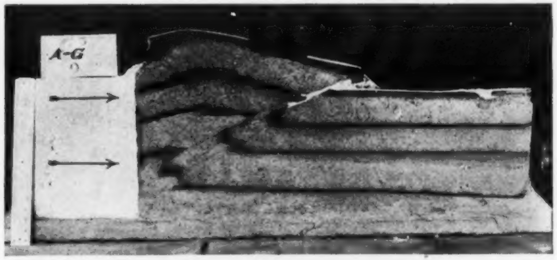

FIG. 17

FIGS. 12-17.—Illustrating six cross sections cut through formation resulting from Experiment 23. For position, see Figure 5. Corresponding explanations of these sections stated under Figures 6-11. Notice difference between type of structure developed in this experiment and that developed in Experiment 20. Courtesy *Imperial Oil Review* (Toronto, July, 1929).

cross section *A-D* (Fig. 8), a different condition is observed. Here are an overthrust fault against the push-block, a broken anticline 10 centimeters outward, and an underthrust fault at the right of this anticline. This underthrust is almost in line with the outer overthrust of sections *A-B* and *A-C*. How would the field geologist map the areas between the cross sections *A-B*, *A-C*, *A-D*, et cetera, if very little or no information were available in regard to these intervening parts? The original photographs and the models show much fracturing in the thicker sand layers which can not be detected in the figures reproduced in this paper. The reader's first thought concerning the results of these experiments may be that nothing comparable could occur in nature. To the reader who adheres to this viewpoint the writer extends an invitation to make a detailed map of parts of the Foothills belt of Alberta.

EXPERIMENT 23 (BRANCHING THRUST FAULTS)

The cross sections of the formation resulting from Experiment 23, in which grease was substituted for the white plaster of Paris layers, show a distinct relationship from section to section. They illustrate a branching of overthrust fault planes not only in cross section but also from section to section in the horizontal plane. That is, they show how a fault plane observed on the surface may bifurcate or split into several smaller faults. There is a great tendency for field geologists, in preparing their maps, to extend an observed fault along the locally determined strike for considerable distances and to join isolated observed faults with those which "line up." A careful study of the sections of this model readily shows that a group of seemingly isolated faults may be connected with one another so that the map will show a network of faults oriented parallel with the grain of the uplift.

To illustrate this, the writer prepared an areal and structural geologic map. For the sake of simplicity, erosion is assumed to have denuded the entire structure produced by Experiment 23 to a featureless plane the level of which corresponds with the top of the second grease layer *M*, as shown in Figure 18. With the information available from cross sections *A-B*, *A-C*, et cetera (Figs. 12, 13, 14, 15, 16, and 17), the areal geologic map shown in Figure 19 was prepared. This map shows the areal extent and boundaries of the beds which would crop out along that plane, the shape of the push-block, some strike and dip readings, and the various faults. The branching habit and the *en échelon* alignment of these faults are particularly noteworthy. The resulting map is not unlike an area selected at random from the Foothills belt of Alberta. In preparing

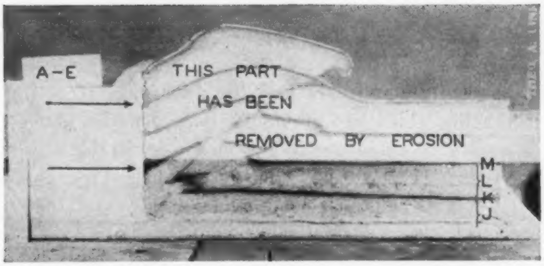

FIG. 18.—Cross section *A-E* through formation resulting from Experiment 23, showing imaginary level or plane to which all of this uplift was eroded before compilation of map illustrated in Figure 19. *J*, *K*, *L*, and *M* are strata which appear on map.

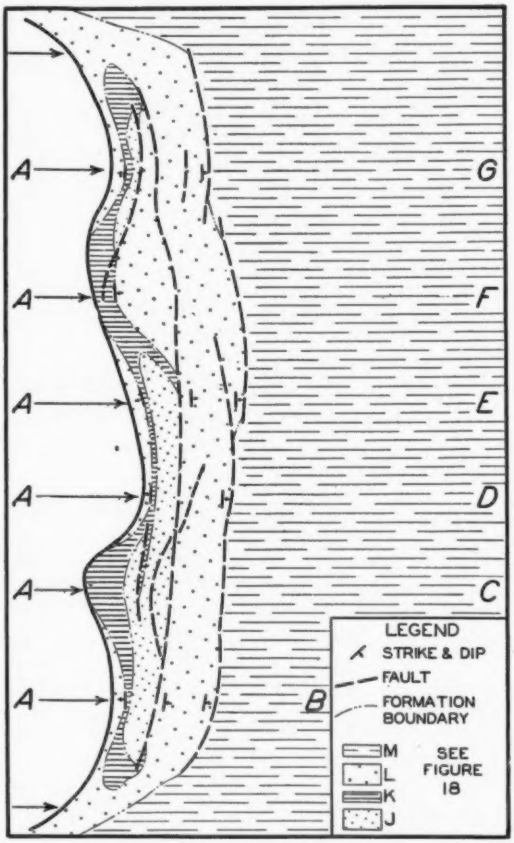

FIG. 19.—Areal and structural geologic map prepared on imaginary plane corresponding with the level of flat part of bed *M* of formation resulting from Experiment 23, as shown in previous figure. Map was constructed on information from original photographs of six cross sections illustrated in Figures 12-17. Plane was regarded as flat or featureless for sake of simplicity. Original photographs show more detail than those reproduced in this paper.

this map, the writer obviously had the advantage of seeing in cross section everything which had previously been denuded above the plane of the map and of having information from a considerable distance below. The field geologist, whose vertical range of observation is ordinarily only a few hundred feet, is never so fortunate. The preparation of similar maps at various horizons of these experiments would be excellent training for students desiring laboratory practice in mapping complicated structural units comparable with those found in the field.[1]

FURTHER DATA ON OVERTHRUSTING AND UNDERTHRUSTING

In the two most widely known American text-books on structural geology[2] no criteria for the differentiation between individual overthrust and underthrust faults are offered except regional considerations.

Regarding this problem Leith[3] states:

> So far as the relationship of the overlying mass to the underlying mass along a thrust plane is concerned, the fault might just as well be called an underthrust fault and the fold associated with it might be called an underdrag or underthrust fold. The term overthrust involves the conception that the overhanging mass has moved forward over a passive mass below, and the use of the term underthrust implies that the underhung mass has been the active and moving one. Some geologists have been inclined to think of underthrusting as an important orogenic process. It is seldom possible to be sure whether a so-called overthrust fault may not really be an underthrust, but probably most geologists incline to the view that most of the occurrences really represent overthrust, on the ground that surficial rocks are known to be more easily deformed and to move more easily than underlying rocks.

In the chapter on "Analysis of Folding," Willis[4] mentions several distinctions between overthrusts and underthrusts based on regional considerations.

> The distinction between overthrusts and underthrusts can sometimes be made on the ground of intensity of deformation. It was shown in the analysis of folding that folds will be more closely compressed on the side toward the source of pressure. In the front range of the northern Rockies great thrust planes are found on which pre-Cambrian and Paleozoic rocks have overridden

[1]The writer will gladly supply anyone with original contact prints of any or all of the experiments.

[2]C. K. Leith, *Structural Geology* (revised edition). (Henry Holt and Company, New York, New York, 1923.)
Bailey Willis and Robin Willis, *Geologic Structures* (revised edition). (McGraw-Hill Book Company, New York, New York, 1929.)

[3]*Op. cit.*, p. 83.

[4]Bailey Willis and Robin Willis, *op. cit.*, p. 290.

Cretaceous and Tertiary sediments from the west. The latter are folded, apparently by the force transmitted in the overthrust itself, or by the drag on its under side. The folds die out eastward. As the area west of them is intensely deformed, the logical inference is that the pressure was from the west. Hence the faults are overthrusts.

The foregoing conclusions are based on the regional considerations, as well as on the results of experiments in folding and faulting performed by Bailey Willis.[1]

EXPERIMENTAL EVIDENCE

From the foregoing quotations from Leith and Willis, it is obvious that no definite criterion for distinguishing between individual overthrusts and underthrusts was given except regional considerations. The latter have caused American authorities on structural geology to arrive at exactly opposite interpretations.[2] The writer believes that if certain information regarding a specific thrust fault were known, it would be possible to determine whether it is an overthrust or an underthrust fault. Furthermore, if this determination could be made on a considerable number of thrust faults in a specified orogenic unit, the question as to the direction in which the forces were operative might be nearer solution, or solved.

In a previous paper,[3] the writer concluded that "underthrust fault planes as a rule develop next to the push-block *at the surface and extend downward no farther than the simultaneously developed overthrust fault plane.*" A further study of these experiments, which include the two described in this paper, and further considerations, have caused the writer to believe that the statement cited could be enlarged and that a more definite contribution regarding the difference between individual underthrusts and overthrusts might be made. An examination of all experiments shows that *overthrust faults invariably develop at depth near the push-block, which is the source of stresses, and exhibit less and less displacement away from the push-block toward the surface* (Fig. 18 and the cross sections in Figs. 12, 13, 14, 15, 16, and 17). An overthrust fault at

[1]Bailey Willis, "Mechanics of Appalachian Structures," *U. S. Geol. Survey 13th Ann. Rept.*, Pt. 2 (1893).

[2]William H. Hobbs, "Mechanics of Formation of Arcuate Mountains," *Jour. Geol.*, Vol. 22 (1914), pp. 166-81.
A. C. Lawson, "Folded Mountains and Isostasy," *Bull. Geol. Soc. Amer.*, Vol. 38 (March, 1927), pp. 253-74.

[3]Theodore A. Link, "The Relationship Between Over- and Under-Thrusting As Revealed by Experiments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 8 (August, 1928), pp. 851-54.

depth may be merely an overturned fold at the surface. The last statement, unqualified, is not new, because many geologists have drawn cross sections showing that to be true, but *a major overthrust at the surface can not disappear toward the source of stresses at depth.* Some individual beds may exhibit more drag than others, but the actual amount of dislocation should increase downward. In almost all the experiments *underthrust faults develop at the surface near the push-block and show less and less displacement away from the push-block, or the source of stresses* (Fig. 19). Thus an underthrust fault may give way to an underfold and finally disappear at depth.

In considering thrust faults one must remember that there are (1) those related to, or caused directly by, the primary stresses, and (2) those of local origin, the result of adjustment in secondary stresses commenced while adjustment is made to the primary cause. In the experiments performed by the writer, almost all the overthrust and underthrust faults can be classified as primary or major thrusts. On the flanks of a fan fold which may develop because of the adjustment of a less competent bed, caught in the core of a major fold between competent strata or series of beds, adjustment by overthrust and underthrust may develop on either side of the fan fold, and the upward or downward extension of such faults may necessarily be limited. Such adjustments or secondary thrust faults are not to be used as guides in determining the direction of the major or primary stresses as outlined in this paper.

Several objections could be offered to the foregoing suggested method of differentiation between primary or major overthrust and underthrust faults. The first is the common objection that laboratory experiments can not duplicate conditions existing in nature. This is a matter of opinion. The extent to which one should use deductions derived from experimental work requires careful thought. A specific objection to the foregoing deductions is the criticism that, because of the rigid floor of the pressure box, almost all relief of pressure must be upward along the overthrust fault plane, because downward movement along the underthrust fault is arrested by the floor of the box. Lawson's[1] paper on the cause and nature of thrusting, in which he showed mathematically that deep shortening must be accomplished by blocks underthrust into the region of heavy rock which cause an elevation of the region affected, is very pertinent to this particular problem. However, the opportunity remains for a difference of opinion as to whether up-

[1] A. C. Lawson, "Isostatic Compensation Considered As a Cause of Thrusting," *Bull. Geol. Soc. Amer.*, Vol. 33 (1922), pp. 337-52.

ward relief in nature is more easily accomplished than a downward plunge of segments into the zone of flowage, where they are assimilated or transferred to an adjoining area undergoing uplift. Because the specific gravity of the materials in the zone of flowage is supposedly greater, and because the rocks in that zone are not only denser, but also under much greater static pressure than those in the zone of fracture, it seems reasonable to conclude that relief of tangential compressive stresses in the zone of fracture would be upward rather than downward. Therefore, the rigid floor of the pressure block does not cause the experimental work to differ much from conditions supposed to exist in nature.

Lawson[1] also stated that because of a progressive increase in friction along an overthrust fault plane, away from the source of stresses, the displacement necessarily becomes less until it finally ends (Fig. 20). There is no doubt that many overthrust faults never reach the surface. It may also be stated that a progressive increase in friction in an underthrust fault plane, away from the source of stresses, will also result in a less displacement until it dies out completely at depth (Fig. 21).

Another objection to the method of distinguishing between overthrusts and underthrusts suggested in this paper is that the necessary

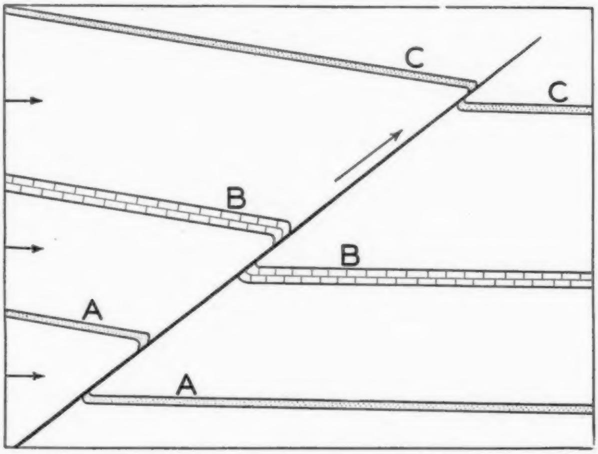

FIG. 20.—Ideal section of simple overthrust fault showing how actual displacement decreases upward along fault plane away from the source of compression. Forces were operative from left to right.

[1] *Op. cit.*, pp. 340-44.

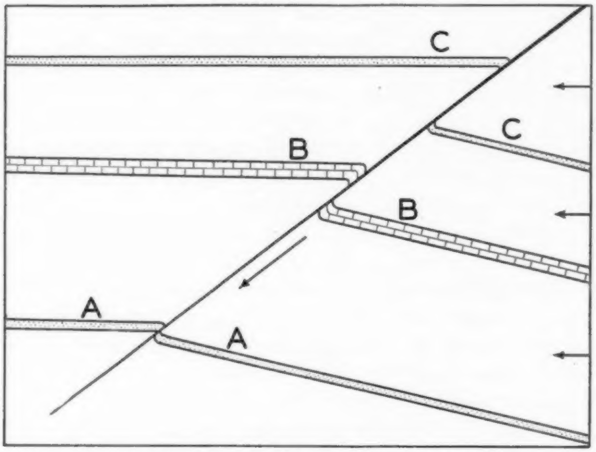

FIG. 21.—Ideal section of simple underthrust fault illustrating how displacement decreases away from source of compression and finally dies out at depth. Forces were operative from right to left.

information is not available in connection with all faults; in fact, it is available for only a few. Therefore, the method is not practical. This objection is becoming less important as drill holes reach greater depths, become more numerous, and are placed to make these determinations. Drilling to a depth of 6,000 feet is no longer considered an exceptional performance, and our knowledge regarding many areas has recently been considerably augmented. The necessary information will, as a result of drilling for oil, be forthcoming. The petroleum geologist will have, and in many matters already has, available information which may solve some of the most important disputes in regard to tectonic geology. A. J. Goodman[1] shows that although the major overthrust fault which underlies the Turner Valley structure of Alberta has a displacement at the surface of less than 700 feet, a displacement of 3,000 feet is indicated at depth. This has not been conclusively proved, as stated in the discussions of that paper, but deeper drilling may give the needed information.

CONCLUSIONS

Experimental evidence indicates the following facts.

[1]A. J. Goodman, "The Turner Valley Gas-Field, Alberta," *Trans. Can. Inst. Min. Met.* (December, 1930), pp. 1505-21, Fig. 1.

1. Slight variations of factors or conditions which influence the growth of structural units may cause extremely diverse results.

2. Diverse combinations of factors or conditions may result in seemingly identical types of structure.

3. Primary or major overthrust faults should show a progressive *decrease* in displacement *upward* toward the surface, away from the source of stresses.

4. Primary or major underthrust faults should exhibit a progressive decrease in displacement from the surface *downward*, away from the source of stresses.

5. Because almost any variety of seemingly improbable or exceptional structures can be produced in the laboratory, the same might also be true in nature; therefore, it is best to map structures *as they are* and not *as they ought to be*.

STRATIGRAPHY OF PERMIAN BEDS OF NORTHWESTERN OKLAHOMA[1]

NOEL EVANS[2]
Tulsa, Oklahoma

ABSTRACT

Heretofore the Day Creek dolomite was supposed to be stratigraphically below the Cloud Chief gypsum. However, detailed work shows that it is above the Cloud Chief gypsum and below the Quartermaster formation. This fact is largely the reason for this paper.

In this paper the Blaine and younger Permian beds are discussed. The Blaine has four gypsum beds and the base of the Blaine is an exact horizon from its northernmost limits in Kansas south at least as far as Fairview, Oklahoma. Nearly all geologists who have traced the Blaine think that the Medicine Lodge member of the Blaine in Kansas is the equivalent of the Ferguson member of the Oklahoma section. It is suggested that, at least for northwestern Oklahoma, the Medicine Lodge member should be made the name of the lowest massive gypsum ledge of the Blaine and that very probably the term Ferguson should be dropped. Above the Medicine Lodge member are three distinct beds of massive gypsum, named, in ascending order: Shimer, Lovedale, and Haskew. The Medicine Lodge and Shimer names were originally used by Cragin. Lovedale and Haskew are names for beds which heretofore have not been named in northwestern Oklahoma.

The Cloud Chief gypsum is removed from its former position as a formation and placed as a member of the Whitehorse. The Whitehorse formation is divided into three members: Marlow, Rush Springs, and Cloud Chief. There are two important horizons in the Whitehorse where limestones or dolomites occur, one at the top of the Marlow and the other near the top of the Rush Springs. The dolomites at the top of the Marlow are called the Relay Creek dolomites, replacing the term "Greenfield," which is preoccupied. The dolomite near the top of the Rush Springs has been named Weatherford dolomite.

The Day Creek dolomite has two members: Upper and Lower Day Creek dolomites. These two dolomites are separated by 1-3 feet of brown to maroon shale. The Day Creek was formerly supposed to occur below the gypsums of the Cloud Chief. In this paper the Day Creek dolomite is placed above the Cloud Chief and underlying the Quartermaster formation.

All the Permian beds of Oklahoma and Kansas above the Day Creek are classified as belonging to the Quartermaster formation. The Kansas terms "Hackberry shale" and "Big Basin sandstone" are dropped, as these beds are correlated with the Quartermaster of Oklahoma.

In northwestern Oklahoma, there are no unconformities of recognizable size from the base of the Blaine to the highest exposures of the Quartermaster. The contacts between these formations are considered to be very nearly exact horizons and the formations are capable of sharp separation.

[1]Read, in part, before the Oklahoma City Geological Society, March 15, 1930. Read before the Tulsa Geological Society, December 15, 1930. Published by permission of the Gypsy Oil Company. Manuscript received, July 22, 1930.

[2]Geologist, Gypsy Oil Company.

INTRODUCTION

Many articles and papers have been published on the stratigraphy of western Oklahoma. The writer wishes to acknowledge that he has had access to most of these various publications and much has been derived from them. He also wishes to state that he has talked with many geologists who have done detailed work in this area. In particular, he has learned much about the Chickasha or south area in discussions with Clyde M. Becker and Roger W. Sawyer. In connection with the north area, he is indebted to G. J. Smith, Carl Barnhart, and Harry Lee Crockett, for their help and suggestions. A bibliography is included.

A considerable amount of confusion seems to exist both in the literature and in the opinions of different men who have worked with the Blaine and younger Permian beds. Much of this seeming confusion probably results from the fact that no one man has had an opportunity to see all these beds, in close detail, in all of this vast area. Many of these papers which have been written cover only a part of this area, and in these papers correlations have been made across great distances without the intervening areas having been examined in detail. As beds can not be expected to carry all of their characteristics through great distances, it is not surprising that a few errors have been made and that there is a difference in opinion concerning these formations.

In the present paper the Blaine formation and younger Permian beds of northwestern Oklahoma are discussed with reference to adjoining areas. This paper is based on detailed and close reconnaissance work done by the writer during the past 4 years. Approximately 2½ years of this time have been spent within the area discussed (Fig. 1). A large part of this work has been done with plane table. The work was done for the former Marland Oil Company and the Gypsy Oil Company. The writer connected and compared his work with that done by other geologists associated with these companies.

Heretofore, the Permian formations of Oklahoma, from the Blaine upward, have been named, in ascending order: Blaine (9),[1] Dog Creek (6), Whitehorse (9), Day Creek (6), Cloud Chief (10), and Quartermaster (9) (Table I). The classification of these beds in southwestern Kansas has been similar, except that above the Day Creek dolomite, the red beds have been called Hackberry shale (6) and Big Basin sandstone (6); also

[1]Numbers in parentheses refer to the publications listed in the bibliography at the end of this paper.

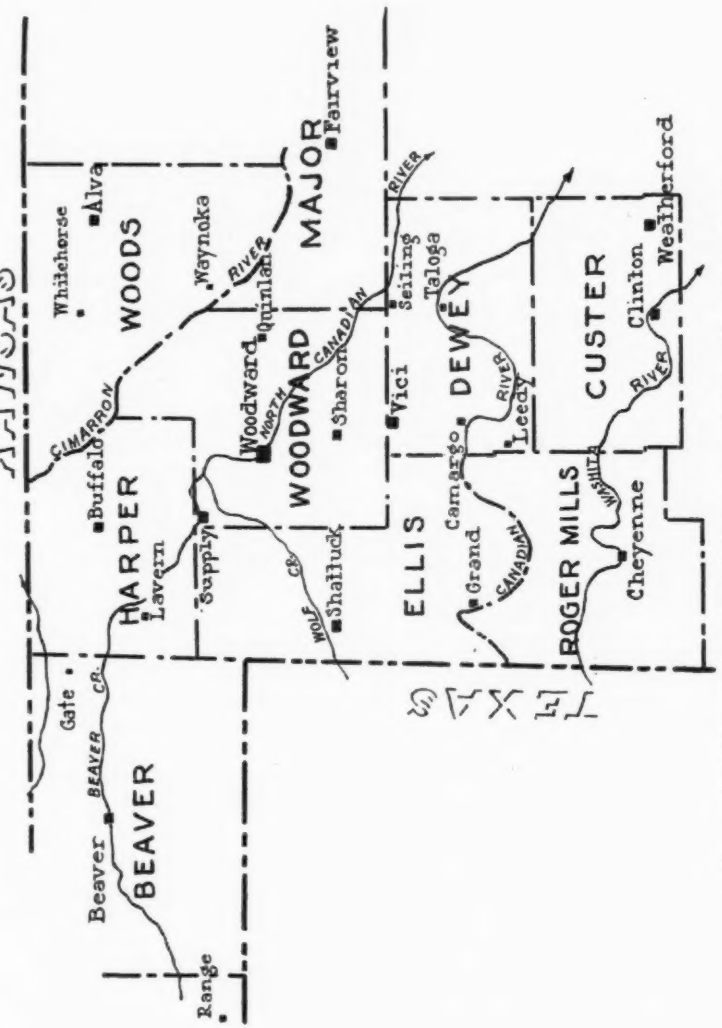

FIG. 1.—Base Map, northwestern Oklahoma. Approximate scale: 1 inch = 28 miles

there are some unnamed red beds which occur above the Big Basin sandstone.

In this paper the writer presents a new classification, but retains as much of the original nomenclature as possible, grouping some of the subdivisions which heretofore have been classed as formations under one main formation name, and dropping the Kansas names for the beds above Day Creek dolomite.

New classification.—The writer includes all the beds from the Blaine upward under five formation names: Blaine, Dog Creek, Whitehorse, Day Creek, and Quartermaster. The Cloud Chief is given a place as a member of the Whitehorse formation (Table I).

TABLE I

CLASSIFICATION OF PERMIAN BEDS, NORTHWESTERN OKLAHOMA

THIS PAPER (1930)		GOULD and WILLIS* (1927)	
Western and Northwestern Oklahoma		*Southern Kansas*	*Central and Western Oklahoma*
Quartermaster formation (Hackberry and Big Basin names are dropped)		Big Basin	Quartermaster
		Hackberry	Cloud Chief
Day Creek dolomite (two beds, Upper and Lower Day Creek)		Day Creek	Day Creek
Whitehorse formation	Cloud Chief member	Whitehorse	Whitehorse
	Rush Springs member Weatherford dolomite		
	Marlow member Relay Creek dolomites (Upper and Lower Relay Creek)		
Dog Creek formation		Dog Creek	Dog Creek
Blaine formation	Haskew gypsum member	Blaine	Blaine
	Lovedale gypsum member		
	Shimer gypsum member		
	Medicine Lodge gypsum member		
Flower Pot shale		Flower Pot	Enid: Chickasha

Bull. Geol. Soc. Amer., Vol. 38 (1927), p. 438.

STRATIGRAPHY

BLAINE FORMATION

The Blaine formation in northwestern Oklahoma has been considered to contain three beds of gypsum with intervening red shale bodies between the gypsum beds. Clifton (5) mentions that in one locality in southeastern Harper County, Oklahoma, there are four distinct gypsum beds. North of Oklahoma in Kansas, there are ordinarily two beds of gypsum recognized in the published reports.

The two beds in Kansas (6) have been named, in ascending order: Medicine Lodge, and Shimer. In Oklahoma (9), the members of the Blaine, in ascending order, have been known as Ferguson, Medicine Lodge, and Shimer. The writer has seen four beds of gypsum in the Blaine in the greater part of Harper and northern Woodward counties, where this formation is exposed.

The base of the Blaine (9) has been considered not to be a plane, but in Kansas to be the base of the Medicine Lodge member, and in Oklahoma to be the base of the Ferguson member, which has been supposed to be below the Medicine Lodge member of Kansas. Snider (19) mentioned that in northwestern Oklahoma, north of the Glass Mountains, there were three beds of gypsum in the Blaine. He raised the question whether the Ferguson of Gould's classification of the Blaine was the lowest of these beds or whether the lowest bed was the Medicine Lodge of Kansas. He did not answer this question, but he did notice the difficulty in the naming of the beds of the Blaine. There is no question that the Medicine Lodge member of Kansas may be correlated with this lowest bed of northwestern Oklahoma as far south as the Glass Mountains straight west of Fairview, Oklahoma.

In 1928, E. C. Parker, Robert McNeely, Ira H. Stein, and the writer, while associated with the former Marland Oil Company, had traced the base of the Blaine from near El Reno north to its northernmost limits in Kansas and were agreed that the base of the Blaine is an exact horizon and that the base of the Medicine Lodge gypsum of Kansas may be correlated with the base of the Ferguson of Oklahoma. However, as the writer has not personally traced the base of the Blaine south of Fairview, he makes no positive statement in regard to the Ferguson, other than that it seems to be the consensus of opinion among geologists who have worked with the Blaine that the Ferguson of Oklahoma is correlated with the Medicine Lodge of Kansas. The writer has traced the base of the Blaine from Fairview north to its northernmost limits in Kansas, several miles northeast of Lake City, Kansas, and the base is an

exact horizon throughout this entire distance. For northwestern Oklahoma, the writer uses the names Medicine Lodge and Shimer for the lower two beds of the Blaine, following Cragin's original nomenclature for these two members. The third gypsum bed is given the name of Lovedale[1] from the exposures of the bed near Lovedale in T. 26 N., R. 20 W., Harper County, Oklahoma. The fourth gypsum bed is named Haskew,[2] from exposures near the old store known as Haskew store at the N. E. Cor., Sec. 2, T. 25 N., R. 19 W.

The Blaine formation of northwestern Oklahoma is described as four distinct beds of white to reddish white, massive, crystalline gypsum, separated by beds of red shale, and with beds of gray dolomite commonly at the bases of the three lower beds of gypsum.

Medicine Lodge gypsum member.—The Medicine Lodge gypsum[3] is commonly 25-30 feet in thickness. The gypsum is white or gray, crystalline, and massive. A gray to almost black dolomite bed, approximately 1 foot or less in thickness, ordinarily underlies this bed of gypsum, and is the horizon that geologists commonly call the base of the Blaine.

Shimer gypsum member.—The Shimer gypsum[4] is in every way similar to the Medicine Lodge, and is separated from the Medicine Lodge gypsum by approximately 20 feet of red shale. The Shimer gypsum is approximately 13 feet in thickness and has a dolomite bed at its base which is very similar to the bed at the base of the Medicine Lodge.

Lovedale gypsum member.—The name Lovedale is taken from the station of Lovedale on the Santa Fe Railroad in eastern Harper County. Good exposures of this bed occur in T. 26 N., R. 20 W. It has been suggested that this third gypsum bed, which is named Lovedale,[5] may be

[1]Name available according to records of the Committee on Geologic Names, U. S. Geological Survey.

[2]Name available according to records of the Committee on Geologic Names, U. S. Geological Survey.

[3]Exceptionally good exposures of this bed occur as the lowest massive gypsum ledge in the southwest bank of Cimarron River, just west of Freedom, in T. 26 N., R. 18 W. Also an easily accessible exposure is in the SW. ¼, Sec. 15, T. 26 N., R. 20 W. (500 feet east of west line and 200 feet north of south line).

[4]A good exposure of the Shimer gypsum is in the SE. ¼, Sec. 16, T. 26 N., R. 20 W., 800 feet north of the road in the west escarpment of Sleeping Bear Creek. The Shimer is well exposed in all of the NE. ¼, T. 26 N., R. 21 W., showing its relationship to both the Medicine Lodge and Lovedale members. This latter location is almost inaccessible.

[5]About 1 mile north of Lovedale station, in the NE. ¼, Sec. 31, T. 27 N., R. 20 W., 500 feet south and 2,300 feet west of the northeast corner, is an exposure of this bed. Another exposure of the Lovedale gypsum is in an outlier some 350 feet southwest of the N. E. Cor., Sec. 23, T. 26 N., R. 21 W.

correlated with the Mangum dolomite of the south side of the Anadarko basin. It seems better to give a new name until such a correlation can be proved. If later it can be shown conclusively that the Lovedale is correlated with the Mangum, then the term Lovedale may well be dropped.

The Lovedale gypsum is approximately 13 feet in thickness and is separated from the Shimer by 7 feet of red shale. It is very similar in appearance to the Shimer and Medicine Lodge. A gray dolomite bed which is ordinarily a little thicker and more prominent than the bed underlying the Shimer underlies the Lovedale. All three of these dolomite beds are commonly pitted and clinker-like in appearance. This feature is more characteristic of the dolomite below the Lovedale gypsum than it is of the other two. Also these lower three gypsum beds are uniformly gray to white with little or no red color. The clusters of interlocking crystals on the weathered surface of the gypsum beds are large.

Haskew gypsum member.—The name Haskew is taken from the abandoned store by this name at the NE. Cor., Sec. 2, T. 25 N., R. 19 W., Harper County, Oklahoma. Although the store is now abandoned, this corner is well known and Haskew seems a suitable name. Good exposures of this fourth gypsum bed of the Blaine occur throughout a great part of T. 25 N., R. 19 W., and a good exposure is in the SW. ¼, Sec. 6, T. 25 N., R. 18 W.[1]

The Haskew gypsum bed commonly differs from the lower three in several particulars. It does not ordinarily have a dolomite bed at its base, although a very impure sandy dolomite has been observed in a few places. This member has a maximum thickness, in Harper and northern Woodward counties, of about 4 feet, and is separated from the Lovedale gypsum by 4 feet of red shale. The clusters of interlocking crystals on the surface of this bed are commonly much smaller than those of the other three beds. Also this bed has considerably more reddish color than the other three.

It seems that some geologists have been inclined to regard a part of the Flower Pot shale (8) and a part of the Dog Creek (15) as belonging to the Blaine. In considering the northwestern area of Oklahoma, where this formation was originally defined, it is difficult to understand why these shales should be included in the Blaine formation. In this paper, the

[1]This exposure is 800 feet east and 200 feet north of the S. W. Cor., Sec.6, T. 25 N., R. 18 W. Above this exposure and immediately northwest is 46 feet of Dog Creek shale; and the base of the Whitehorse makes a good exposure in the grader bank of the road 1,600 feet north of this section corner.

Blaine formation is considered to include the beds between the base of the dolomite bed underlying the lowest massive gypsum ledge (Medicine Lodge) and the top of the fourth (Haskew) gypsum ledge. According to this definition, the Blaine formation of northwestern Oklahoma, at the surface, is approximately 90 feet in thickness.

Glenn C. Clark and Stuart K. Clark of the Continental Oil Company have furnished the writer with two logs of the Blaine taken from two of their core drill holes in Ellis County, Oklahoma. In these core logs, four beds of Blaine gypsum can be separated. The lowest bed (Medicine Lodge) has a small break of gray shale, and above the fourth bed (Haskew) occur two or three thin beds of gypsum in the Dog Creek shale. In Figure 2, these core logs are compared with the surface measurements taken from the outcrops in Harper and northern Woodward counties. Some may question whether the lowest bed of the core logs, containing the small shale break, should be correlated with the Medicine Lodge member of the exposure. The writer is sure of this correlation. He has had access to other core logs which occur at intermediate points between the two logs given in this section and the exposures. For obvious reasons it is not practical to publish all these logs.

There may be some question as to the correctness of including four beds of gypsum in the Blaine, inasmuch as the Blaine was originally described as having three beds. The rules of nomenclature permit the redefinition of an aggregate without a change of name. In regard to this point the writer quotes from Stanton's recent article on stratigraphic names,[1]

> ....the redefinition of an aggregate does not necessarily render renaming advisable.
>
> The exceptions recognize the facts: (1)....(2) that minor modifications of the boundaries of a unit of any rank may be made without necessarily changing the name of the unit.

DOG CREEK FORMATION

The Dog Creek formation in Harper and northern Woodward counties consists of approximately 50 feet of red shale, a few beds of soft red sand, and two or three thin beds of gypsum near the base of the formation. The shale is gypsiferous; the sand is poorly cemented, reddish buff, commonly with dots of white. The two or three beds of gypsum, near the base, are of the nodular crystalline type, and are not ordinarily more than 6 or 8 inches thick.

[1] T. W. Stanton, "Stratigraphic Names," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), p. 1078.

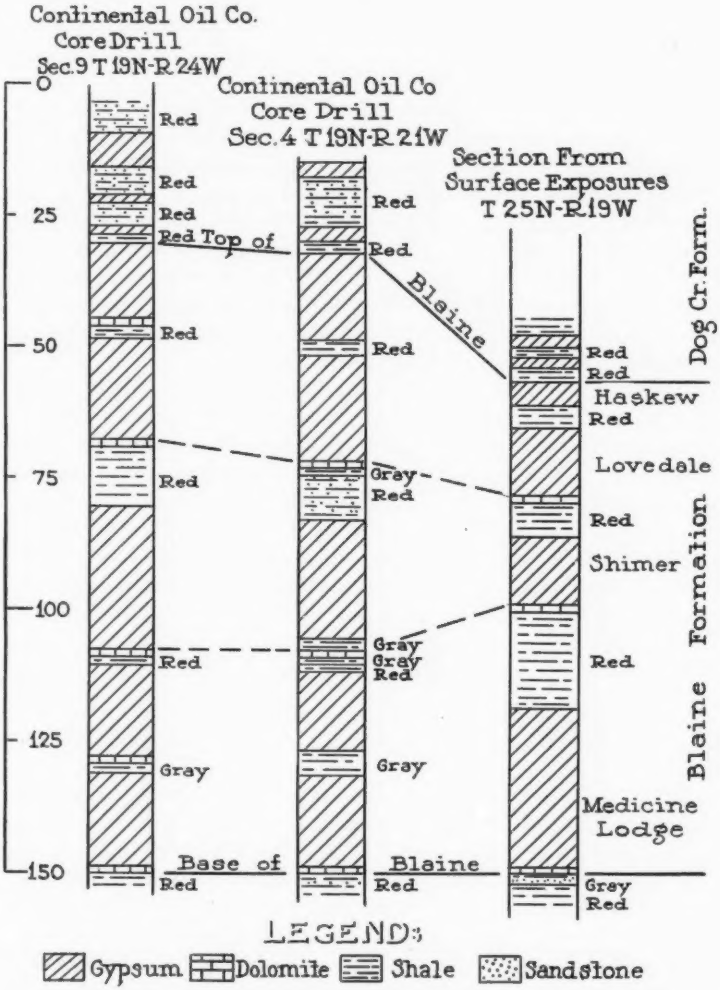

FIG. 2.—Blaine formation as revealed by core drill in Ellis County, Oklahoma, compared with exposures in northeastern Woodward County. Vertical scale in feet.

Near Quinlan, this formation is approximately 60-65 feet in thickness, and increases southward to the vicinity of the Anadarko basin, where its thickness is probably 175 feet or more. This increase in thickness seems to occur throughout the entire formation and is not the result of overlap or unconformity.

In Harper and northern Woodward counties there is a white or powder-blue bed approximately 2 feet thick, with thin, non-persistent dolomite stringers, which occurs almost in the middle of this formation. This powder-blue, soft, dolomitic sandy bed is very persistent and can be traced to the vicinity of Quinlan, where it is the middle white streak between two similar white zones. Throughout Harper County the Dog Creek formation is notably persistent in its thickness of approximately 50 feet. The change in thickness does not occur until the formation is traced southward and in this direction the increase is gradual, indicating a depositional thickening of the beds.

In the accompanying figure of the Blaine in the core logs (Fig. 2), the gypsum beds of the lower part of the Dog Creek formation are shown. In this connection it might be said that the Dog Creek formation is very closely allied with the Blaine (15) and farther west may merge with the Blaine to make a very considerable thickness of gypsum. As the Dog Creek is supposed to lose its identity westward and southwestward from northwestern Oklahoma, this seems a logical explanation of what happens to the Dog Creek. However, as these two formations have long been recognized as such in Oklahoma, they are considered to be two distinct formations.

WHITEHORSE FORMATION

The Whitehorse formation is divided into three members which are, in ascending order, the Marlow (17), the Rush Springs (18), and the Cloud Chief.

The Whitehorse formation of Harper and northern Woodward counties consists of approximately 250 feet of reddish buff sand, red to maroon shale, and a few white to reddish crystalline gypsum beds. The sandstones are soft, poorly cemented, and fine-grained. In this north area the lower 100 feet of the Whitehorse is entirely sand except for a non-persistent bed or two of gypsum; the upper 150 feet contains a considerable amount of shale and six or seven beds of reddish white crystalline gypsum. The amount of shale and gypsum increases toward the west and southwest.

The limestones or dolomites of the Whitehorse formation may be said to occur at two general horizons: the Relay Creek dolomites at or

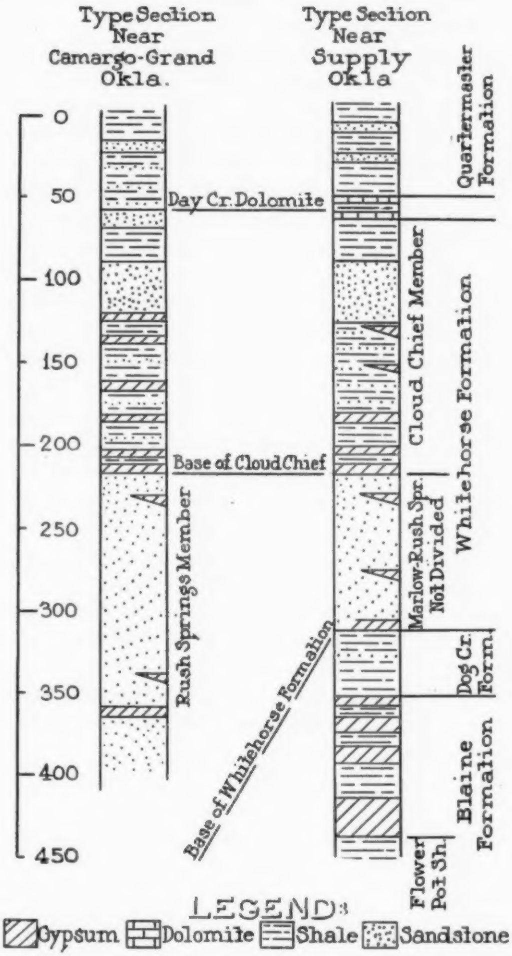

FIG. 3.—Geologic section north of Supply, Oklahoma, compared with section in Camargo-Grand area. Vertical scale in feet.

near the top of the Marlow member, and the Weatherford dolomite near the top of the Rush Springs member.

Relay Creek dolomites.—The dolomites at or near the top of the Marlow member have been known as the "Greenfield" dolomites, but this name is preoccupied and it seems well to offer a new name. The name Relay Creek[1] is suggested for these beds. The type area for these beds is the same as that for the "Greenfield," in the hills west of the town of Greenfield, Oklahoma.[2] More specifically, the type area is both north and south of Relay Creek, in T. 15 N., R. 12 W., and adjoining townships on the south and east. There are ordinarily two beds of dolomite separated by approximately 25 feet of red sandstone and shale. Each bed is a foot or two in thickness, but in other areas the thickness decreases to almost nothing. Locally there is a third bed of dolomite 7 or 8 feet below the lower of the two mentioned. The two beds commonly occurring are here designated as Upper Relay Creek and Lower Relay Creek dolomites. The third, or lowest, bed is associated so closely with the Lower Relay Creek dolomite that it is merely mentioned, with no distinguishing name. The color of these dolomites varies from light gray where the beds are a foot or two in thickness to almost black where the beds are very thin. In the type area, where the thickness is almost the maximum observed for the beds, the color is gray.

Weatherford dolomite.—The Weatherford dolomite is a gray dolomite bed 60 feet or less below the top of the Rush Springs member. Just southwest of the town of Weatherford this interval was observed to be approximately 60 feet, but farther south the interval from the Weatherford to the base of the lowest massive bed of Cloud Chief gypsum decreases to 25 feet or less. In lithologic appearance, the Weatherford resembles very closely the Relay Creek dolomites.

Marlow and Rush Springs members.—In discussing these members of the Whitehorse, it seems well to mention their definition in their type areas first. Roger W. Sawyer[3] first defined these members, and he gave definite limits which should be followed as long as these limits are found

[1]Name available according to records of the Committee on Geologic Names, U. S. Geological Survey.

[2]A readily accessible exposure of these dolomites is about 1,800 feet southwest of the N. E. Cor., Sec. 25, T. 15 N., R. 12 W. The Upper Relay Creek dolomite makes the highest scarp and the Lower Relay Creek dolomite is about 26 feet lower in elevation.

[3]Roger W. Sawyer, "Areal Geology of a Part of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (May-June, 1924), p. 313; "Kiowa and Washita Counties," *Oklahoma Geol. Survey Bull. 40-HH* (1929).

to be practical. The Rush Springs is the unit that Reeves[1] called "Whitehorse" in his report on the Cement field. The base of the Rush Springs is, by definition, a gypsum bed. The top of this gypsum is the contact between the Marlow and Rush Springs members of the Whitehorse. There may be some question as to whether this gypsum is in the horizon of the Upper Relay Creek dolomite or of the Lower Relay Creek dolomite. At any rate it seems that the consensus of opinion is that this Marlow-Rush Springs contact should be drawn at the top of the Upper Relay Creek dolomite. The base of the Marlow is the top of the Dog Creek shale and where exposed this is a definite and easily recognized contact. The top of the Rush Springs is the base of the Cloud Chief. In the discussion of the Cloud Chief this contact is defined specifically for northwestern Oklahoma. In the northwestern Oklahoma area it is not possible to separate the Marlow from the Rush Springs member. Together, they constitute the lower 100 feet or more of Whitehorse as this formation is exposed in Harper, northern Woodward, and western Woods counties. This lower subdivision of Whitehorse is entirely sandstone with the exception that in places a gypsum ledge 2 feet in thickness occurs at the base, and farther west a gypsum bed that attains a thickness of 5 or 6 feet occurs 20-35 feet above the base. This sandstone is of the characteristic Whitehorse color and appearance. In this part of the Whitehorse occur some of the so-called channel sands. These channel sands occur at irregular intervals above the base of the formations. Inasmuch as the channel sands of the south area occur near the top of the Marlow, one might think that the channel sands of Woods and Woodward counties also occur near the top of the Marlow. However, this is not necessarily true, as these so-called channel sands occur in places only a short distance above the base of the lower 100 feet, as at Whitehorse Springs, Oklahoma. In Sec. 13, T. 24 N., R. 19 W., they occur 100 feet or more above the base, or at the top of this lower division. A bed of this type occurs approximately 40 feet below the Day Creek dolomite in Sec. 29, T. 24 N., E. 18 W., and in the area east of Woodward. In connection with these so-called channel sands, it might be suggested that much of their characteristic appearance is caused by the calcitization which has occurred. They have their best development where overlying beds have been removed by erosion. They seem to range in thickness from almost nothing to possibly 50 feet. This maximum thickness was observed near the center of Sec. 13, T. 24 N., R. 19 W.

[1]Frank Reeves, "Geology of the Cement Oil Field, Caddo County, Oklahoma," *U. S. Geol. Survey Bull. 726-B* (1921).

FIG. 4.—Sec. 13, T. 24 N., R. 19 W., Oklahoma. So-called channel sandstone near top of Marlow-Rush Springs member of Whitehorse. Approximately 50 feet in thickness.

In regard to this calcitization, the writer has taken a piece of the channel sandstone and, after dissolving all the calcite and dolomite in hydrochloric acid, has found the sand grains to be larger than most of the Whitehorse grains, but still somewhat fine-grained. In some pieces, the proportion of calcite is probably 75 per cent. Aside from the calcitic nature of these sands, they are similar to the normal type of Whitehorse. It is not to be understood that this calcitization completely explains these beds. Very probably, there are depositional reasons for these so-called channel sands. The fact that the sand grains are larger than those commonly found in the Whitehorse sands indicates this. The writer offers no explanation of the depositional conditions under which they were formed. The fossils of the Whitehorse are found in these beds. The fact that these beds are calcitic possibly is the reason for the fossils in such soft, poorly cemented beds as the ordinary type of Whitehorse. The writer considers all the beds of the Whitehorse in the northwestern Oklahoma area to have been deposited in water and not above the water-level.

The writer concludes that the so-called channel sands are of no value for correlation purposes, as they occur at different horizons in the Whitehorse; also they differ greatly in thickness in very short distances.

With the exception of the channel sandstones, there is very little cross-bedding in this part of the Whitehorse, which is in contrast to

the cross-bedding of the Rush Springs member near Weatherford. Also the lack of shale beds is in contrast to the shale beds of the Marlow of the south area. However, one shale bed occurs in the lower part of this section near the town of Quinlan.

At the top of this Marlow-Rush Springs subdivision northwest of Woodward, is a double gypsum bed marking the base of the Cloud Chief gypsum. East and northeast of Woodward, the top is commonly marked by a calcitic or dolomitic bed which ranges from almost nothing to a foot or more in thickness. At one place mentioned previously, this horizon is a so-called channel sand which is nearly 50 feet in thickness. It is suggested that this calcitic bed, normally a few inches thick, may be approximately correlated with the Weatherford dolomite of the Weatherford area.

Clifton (5) and others have suggested that an unconformity exists at the base of the Whitehorse, or at the base of the Marlow-Rush Springs as we are describing this member. The writer has never seen the Whitehorse resting, in place, on any bed lower than the top of the Dog Creek and has observed nothing, except changes in intervals, to suggest such an unconformity. As these interval changes can easily be explained by depositional thickening and thinning of beds, there is no need to postulate truncating by an unconformity to explain them. It seems that most, if not all, of the Permian beds thicken toward the south or southwest from the Kansas-Oklahoma line and the writer believes the Marlow-Rush Springs members follow this rule. Being almost entirely composed of sand, they could reasonably increase their thickness five times, as shale bodies are known to increase almost that much. Examples of these shale bodies are the Flower Pot and the Dog Creek. Few, if any, geologists would postulate an unconformity for each of the Permian formations which greatly increase in thickness at their southern exposures.

As the Marlow member of central-western Oklahoma is persistent in thickness, approximately 100 feet, it may be suggested by some that all of the lower 100 feet of Whitehorse of northwestern Oklahoma, which the writer classifies as Marlow-Rush Springs, should be Marlow. This 100 feet is entirely sand with the exception of a very few non-persistent gypsums and has no other recognizable breaks in its entire thickness. It is impossible to divide this lower 100 feet; and it is equally impossible to show that the Rush Springs has completely lensed out before reaching northwestern Oklahoma, which would be necessary if the entire 100 feet is Marlow. It is entirely within reason for both members to be represented in this 100 feet and the writer prefers so to consider them, until

it can be demonstrated that either the Rush Springs or the Marlow has completely lensed out.

Cloud Chief member.—Many may wonder why the Cloud Chief gypsum, which formerly has been given formation distinction, should now be classed as a member of the Whitehorse. The reason is that the base of the Cloud Chief horizon occurs near the middle of the Whitehorse sandstone as originally described by Gould.[1] Gould's type area for the Whitehorse is near Whitehorse Springs, 20 miles west of Alva, Oklahoma. Whitehorse was the name given to take the place of Cragin's Red Bluff sandstone, and includes the sandstone, shale, and gypsum occurring between the Dog Creek shales and Day Creek dolomite. At this place, there is very little shale and there are no beds of crystalline gypsum in the Whitehorse. According to Ben H. Parker,[2] a gypsum bed or two occurs in this formation 12 miles northwest of Whitehorse Springs, about 1,000 feet northeast of the SW. Cor., Sec. 15, T. 28 N., R. 18 W., and a short distance east of the center of Section 21, of the same township. Both the Day Creek dolomite and the Dog Creek shale can be easily traced west to a point 15 miles north of Woodward, Oklahoma. Here occur three or four beds of crystalline gypsum near the middle of the Whitehorse. At this same locality are two gypsum beds, each about 2 feet thick, separated by a foot or two of maroon shale. The lower of these two gypsum beds rests on sandstone, which is about 100 feet thick and contains no shale breaks. This double gypsum bed is correlated with a double gypsum bed immediately above a great thickness of sand at Camargo, Oklahoma. The double gypsum bed at Camargo marks the base of the Cloud Chief so far as we are now able to decide. It occurs both east and west of Camargo. Near Camargo and north of Woodward, there are non-persistent gypsum beds below this double bed, but they have sand both immediately above and below them. This is a distinguishing point in determining the Cloud Chief limits. Gypsum beds below the double bed are not considered to be a part of the Cloud Chief, but are a part of the Rush Springs member. North and northwest of Woodward there are beds of gypsum above the double bed. These higher gypsums correspond approximately with higher beds of the Cloud Chief which occur above the double bench near Camargo. Gould, in his original definition and description of the Cloud Chief,[3] does

[1]C. N. Gould, "Geology and Water Resources of Oklahoma," *U. S. Geol. Survey Water Supply Paper 148* (1905).

[2]Ben H. Parker, personal communication dated March 18, 1930.

[3]Charles N. Gould, "A New Classification of Permian Redbeds of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (May-June, 1924), p. 337.

FIG. 5.—Basal Cloud Chief, Sec. 13, T. 26 N., R. 24 W., Oklahoma. Notice "double gypsum" beds with shale between two beds, shale above upper bed, and sandstone below lower bed. The gypsum at top of picture is 18 feet above the "double gypsum."

not exactly define its top, nor is it clear exactly where the base should be. In regard to its base, he states:

> It lies above the Day Creek dolomite where the former is present, or, if the Day Creek is absent, it is next in succession above the Whitehorse sandstone.

In the foregoing quotation, the term "Whitehorse sandstone" refers to the beds classified in this paper as the Rush Springs member of the Whitehorse, and the term "Day Creek" refers to the dolomite classified in this paper as Weatherford dolomite. For some time there has been a question as to where the Rush Springs should end and the Cloud Chief begin. The reason for this uncertainty is that gypsums of the Cloud Chief type occur in the Rush Springs, and sands very similar to the Rush Springs occur in places in the Cloud Chief. So far as the writer knows, and so far as the literature states, there is no place where gypsum can be found resting directly on the Weatherford dolomite. In the type area of the Weatherford, near Weatherford, Oklahoma, where beds overlying this dolomite can be found, those immediately above the dolomite are consistently of sandstone. The massive beds of gypsum occur 20-60 feet above this dolomite. It is true that a few lenticular beds of gypsum occur in this interval, but in some places it seems to be entirely sandstone. In this paper the point is stressed that the contact of the Cloud Chief with the Rush Springs should be definitely placed at the base of

the lowest gypsum bed, which rests on a great thickness of sandstone and above which occurs shale. This is in line with the original description of the Cloud Chief given by Gould. He is further quoted.

> The Cloud Chief formation consists of ledges of massive gypsums imbedded in red shales.....In some places, as for instance near Cement, there are, according to Reeves, two beds separated by 15 to 20 feet of gypsiferous shale. ....In other localities three or more gypsums, separated by clay shales, outcrop on the surface.

As it is impossible to differentiate between the gypsums except on the basis of sequence of beds, this shale and sandstone contact is the only definite criterion on which an exact separation can be made.

North of Woodward and west to R. 25 W., these gypsums are known to occur and can be definitely correlated. Gypsums in this zone occur farther west in Beaver County along the south side of Beaver Creek. Gould and Lonsdale (12), in their Bulletin on Beaver County, point out that these exposures are typical of Cloud Chief stratigraphy. There can be no question that these beds are a part of the upper Whitehorse and below the Day Creek dolomite horizon. In Beaver County at least seven gypsum beds occur in this member of the Whitehorse. The Day Creek horizon has been found above these beds 8 miles southeast of the town of Beaver.

Through this north area in Harper County, above the double gypsum and below the Day Creek dolomite, shale and sand occur in approximately equal proportions. From a point 15 miles north of Woodward, the amount of shale and gypsum increases toward the west and southwest. Shale and gypsum decrease toward the east and southeast, and the gypsum becomes entirely absent in a very few miles. This upper 150 feet of Whitehorse is classified as the Cloud Chief member of the Whitehorse formation. In this classification, 50 or 60 feet of sandstone and shale above the gypsum beds is included in the Cloud Chief. Gould, in his type area of Cloud Chief, does not seem to include any sand and shale above the gypsums, but he does not definitely establish a limit for the top of this member. In the interest of simplicity, and also because these higher sand and shale beds in places contain gypsum and because they are very similar to the lower Cloud Chief sands and shales, they are here placed in the Cloud Chief member. This is permissible under the rules of the Committee on Geologic Names of the United States Geological Survey. In this connection, the writer quotes T. W. Stanton, chairman, Committee on Geologic Names.[1]

[1]T. W. Stanton, personal communication dated November 25, 1930.

It is always considered regrettable to have to redefine a formation whose limits have been definitely fixed, and in general if the content of the formation is greatly changed a new name should be given. Minor shifting of boundaries and other modifications that are sometimes required to make a formation or other unit a natural one are permitted without a change of name.

Near the old town of Grand, Oklahoma, in Sec. 19, T. 17 N., R. 24 W., the Cloud Chief was measured from the base of the double gypsum bed to the top of the highest gypsum and found to be about 90 feet. Above these gypsums, near Grand, occur beds of sand and shale which are estimated to be 40-50 feet in thickness. On account of erosion, the total thickness of these sands and shales has not been accurately determined.

It might well be stated that in the 150 feet assigned to the Cloud Chief, northwest of Woodward, there occur at least four beds of gypsum above the double bed, and west of Camargo there are at least five beds above the double bed. In both localities, shale and some sand occur between the different beds. Seemingly, more shale is in the Camargo-Grand area than northwest of Woodward. In Beaver County, south and southwest of the town of Beaver, this zone is almost entirely shale and gypsum. In this same connection, it can be stated that in many places the horizon of a gypsum bed seems to be replaced by a bed of soft white sand or possibly sand filled with gypsite. The white coloring in the Whitehorse formation seems to be a characteristic of gypsiferous horizons.

Sandstone and shale in the Cloud Chief above the gypsums.—Up to the present time, the writer has not seen a place in the Camargo-Grand area where the entire thickness of sand and shale beds above the gypsums can be accurately measured. The Day Creek dolomite horizon has been found, but exposures between the highest gypsum bed of the Cloud Chief and the Day Creek are too poor to be accurately measured. Immediately above the highest gypsum of the Cloud Chief of this area is a bed of massive, soft, characteristic Whitehorse sand 25-30 feet in thickness. Above this sand has been observed 15 feet of shale and thin sand beds. This thick massive sand bed resembles, in most respects, the bed 25-30 feet below the Day Creek horizon and is now tentatively correlated as such. If this tentative correlation is correct, the sand and shale above the gypsum are approximately 60 feet in thickness. In the north area the thickness is approximately the same.

This massive bed of sand, the top of which is 25-30 feet below the Day Creek dolomite, is a very important horizon. Except in south-

western Beaver County, where this zone is largely red shale, it has been found everywhere below the Day Creek, if erosion conditions have been such as to expose it. Though the bed of sand itself is persistent, its top or the first few feet above its top varies a great deal. The top is commonly characterized by two calcitic or dolomitic zones each of which is an inch or two in thickness. One of these calcitic zones rests on the sandstone and the other is ordinarily 1-3 feet above the top of the sand. Between the two calcitic beds is shale which is commonly calcitic, giving the impression of shale conglomerate. No other sand has been observed to have two calcitic beds at its top.

In a few places the top of this massive sand is marked by a bed of gypsum 3 or more feet in thickness. This gypsum occurs in Sec. 23, T. 25 N., R. 22 W. Also 2 or 3 miles west of Supply, on Oklahoma Highway 33, there is gypsum in this horizon.

Another characteristic noted for this horizon is 2 or 3 feet of purplish platy beds immediately overlying the massive sandstone. These platy beds are well exposed a mile or two southwest of Supply.

In places a white streak marks the top of this sand, and at other places there is only the contact between shale and sand. East of Woodward, a so-called channel sand occurs a few feet down from the top of this sand. This so-called channel sand is probably caused largely by calcitization of the bed.

The top of the Cloud Chief is definitely determined at the base of the Day Creek dolomite horizon, which is 25-30 feet above the massive sandstone.

Clifton (5) suggests that the zone above this massive sand and below the Day Creek dolomite is a zone of unconformity or series of unconformities. Immediately above this sand is the zone which has the various types of beds: gypsum, calcitic or dolomitic stringers, and purple platy beds. This condition may, to a certain extent, suggest a very small unconformity or disconformity. Since the higher beds are, for all practical purposes, conformable over this massive sandstone, it does not seem advisable to the writer to designate this zone as one of unconformity. The writer has traced this zone from the northwestern corner of Harper County, Oklahoma, to the area south of Vici and found it to range in thickness from 20 to 31 feet, but this variation in thickness is gradual. Sandstone beds immediately below the Day Creek are very persistent in their characteristics in most of this area. Between these sandstone beds and the top of the massive sand is a zone of 10-20 feet of red shale. Nothing suggestive of an unconformity, except the various types of beds at the top of the massive sand, has been observed in this zone.

Nomenclature of Whitehorse.—In view of the fact that the Cloud Chief is, in this paper, included in the Whitehorse formation, it might seem to some geologists that the writer should propose new names for certain, if not for all, of the beds considered as belonging to the Whitehorse. The writer has had opinions from several geologists and most of these men are of the opinion that the old names should be used, if there is no conflict with the established rules of nomenclature. The writer wrote Miss Wilmarth of the Committee on Geologic Names for the United States Geological Survey for an opinion on this matter and received a reply from T. W. Stanton,[1] chairman of this committee. A part of Stanton's letter is quoted.

> If the facts concerning the stratigraphic units Whitehorse and Cloud Chief are as you state them and if the larger unit is of formation rank, it would be reasonable to treat Cloud Chief as a member of the Whitehorse formation.

The writer considers the aggregate called Whitehorse in this paper to be of formation rank, but if later it can be established that it should be classed as a group and the different members should be given formation rank, the changes of rank may be made then without changing the geographic part of the name. This is in accordance with the accepted rules of nomenclatural practice.

As all the beds treated by the writer as Whitehorse are very closely allied, and as their stratigraphic equivalents were originally included in Gould's Whitehorse sandstone, there is no good reason to add to the already existing confusion by offering a new name for the Whitehorse. As the only possible addition to what Gould originally termed Cloud Chief is 50-60 feet of sandstone, shale, and gypsum which is in all respects similar to the other Cloud Chief beds, and as this is necessary to make the unit a natural one, the writer insists that there has been no violation of the established rules of nomenclature, and believes that this grouping of the beds and this naming of the members of the Whitehorse are fitting and proper.

DAY CREEK DOLOMITE

The Day Creek dolomite was originally described by Cragin from exposures of the bed in central Clark County, Kansas. This type area is 25 miles northwest of Buffalo, Oklahoma. Here the Day Creek is a hard, light gray limestone or dolomitic limestone, 2 feet in thickness. Characteristic Whitehorse sand and shale are below it, and above is the dark red or maroon shale, which makes a contrast in color to the reddish buff

[1]T. W. Stanton, personal communication dated November 25, 1930.

of the Whitehorse below. In this type area, the Day Creek commonly contains aggregates of smoky or reddish chert.

In Oklahoma, particularly in eastern Harper, western Woods, and northeastern Woodward counties, this same description applies to the Day Creek. Here, however, occurs a pinkish or purplish calcitic or dolomitic bed, about 3 inches in thickness, 3 feet above the Lower Day Creek dolomite. It seems well to include this upper thin dolomite bed as a part of the Day Creek and it is here called the Upper Day Creek dolomite and the lower bed which was called originally the Day Creek is here called the Lower Day Creek dolomite. Brown shale, weathering maroon, separates these two dolomites. It is not recalled whether this Upper Day Creek bed occurs at the type area in Clark County, Kansas, but it probably does, as it is widespread in its exposures in northwestern Oklahoma. Unless removed by erosion, this Upper Day Creek dolomite can almost everywhere be found above the horizon of the Lower Day Creek.

West and south of Supply, the Lower Day Creek becomes very sandy and even grades into sandstone. In many places there is no indication of calcium carbonate. In some places the horizon is marked by a white streak on top of the characteristic reddish buff sandstone, and at other places there is merely the reddish buff sand itself. The Upper Day Creek bed occurring above makes this correlation positive.

The Day Creek dolomite horizon can be traced on the south side of North Canadian River from a point south of Laverne, east, to correspond with good characteristic Day Creek dolomite or limestone exposures east of Woodward.

From a point about 7 miles southeast of Woodward, it is very difficult to trace the Day Creek southward because of the Quaternary and Tertiary overlap. However, there is a good exposure of this horizon in the SW. ¼, Sec. 14, T. 21 N., R. 20 W., 1 mile east and 1 mile north of the town of Sharon. The top of the Whitehorse formation, with overlying maroon shale, occurs 2 miles south of Vici, in the NW. ¼, SE. ¼, Sec. 23, T. 19 N., R. 20 W.; also in the SW. ¼, Sec. 24, of this same township. At these two places, the Lower Day Creek horizon is merely the top of the Whitehorse sandstone, and the Upper Day Creek bed is poorly exposed, but the massive Whitehorse sand bed 30 feet below the Day Creek is present, and above this sand occur the two characteristic calcitic beds. These calcitic beds do not occur everywhere above this sandstone, but they commonly do occur, and such beds have nowhere been observed by the writer to occur above any other bed of sand. The writer makes

this correlation very positively, in spite of the fact that the Upper Day Creek is poorly exposed at these points. The question has been raised whether the regional dip of this area indicates that this correlation of the Day Creek is in error. It is true that the regional dip of the base of the Blaine is southward, and south of Vici the base of the Blaine is approximately 300 feet lower than it is 15 miles north of Woodward, whereas the Day Creek has about the same elevation at both places. This is explained by the fact that the Blaine, Dog Creek, and Whitehorse all thicken so that this increased thickness accounts for the divergence of dip. All geologists are aware of the fact that such divergences in dip are not at all uncommon.

QUARTERMASTER FORMATION

The Quartermaster formation includes all the Permian Red-beds of Oklahoma and Kansas above the Day Creek dolomite. This formation is composed of dark red or maroon shale, and red or red and white sandstone. There are white streaks in the shale and commonly at the tops and bottoms of the different sandstone beds. By far the greater part of the Quartermaster is shale, which is uniformly dark red or maroon and of the blocky type. The sands are ordinarily thin, only an inch or a few inches thick, and break commonly into little rectangular blocks. There are some sands which attain a few feet in thickness; and near the base of the formation there are a few sandstone beds which are soft and of the same color as the Whitehorse. However, these sands are not easily confused with the Whitehorse where good exposures occur, because of the intervening maroon shale and the sequence of beds.

"Hackberry shale" and "Big Basin sandstone."—In Kansas and northwestern Oklahoma, north of Canadian River, the Quartermaster beds, heretofore, have been called "Hackberry shale," "Big Basin sandstone," and there are some unnamed red beds which occur in places above the Big Basin sandstone. These unnamed red beds are mostly shale with a few sand beds. Even in Oklahoma, north of Canadian River, it is in very few places, if any, that more than 75-100 feet of red beds above the Day Creek dolomite are exposed. These exposures ordinarily range from a few feet to 60 feet in thickness.

The "Hackberry shale" is described as a maroon blocky shale, and the "Big Basin sandstone" as a series of red, white, or red and white particolored sandstone beds which range from a few inches to 4 feet in thickness for each bed. Shale in all respects similar to the "Hackberry" occurs between the "Big Basin" beds, and also above them. There seems little reason to give two names to these beds, as the "Big Basin"

FIG. 6.—Quartermaster (Big Basin). Notice particolor (red and white) characteristic of Quartermaster beds. Sec. 14, T. 25 N., R. 22 W., Oklahoma.

FIG. 7.—Quartermaster (Big Basin) beds. Sec. 24, T. 24 N., R. 24 W., Oklahoma. Exposure 25 feet above Day Creek dolomite horizon.

type sands occur almost anywhere above the Day Creek and the same type of shale occurs above and below these "Big Basin" sandstones. The chief characteristics of this part of the Quartermaster are the type of shale and the particolored nature of the sandstones. The sandstones are commonly better bedded and harder or better cemented than the underlying Whitehorse sandstone. This particolored feature occurs in places in the Whitehorse, but can truly be called a characteristic of the Quartermaster formation. These "Hackberry-Big Basin" beds traced southward are correlated with part of the Quartermaster, and are below what is commonly known as the thin, platy beds of the Quartermaster.

In some of the articles written on western Oklahoma, these Quartermaster beds are said to be gypsiferous. The writer has never seen gypsum, as beds, in either the "Hackberry-Big Basin" exposures or in the higher Quartermaster beds. From all the exposures of these beds that he has seen, he supposes either that these beds have been miscorrelated or that this so-called gypsum forms the thin laminae which occur in the shales. These laminae are somewhat similar to the satinspar gypsum which commonly occurs in shale. However, the writer has found all these laminae of the Quartermaster to be calcite or aragonite, and not gypsum.

Quartermaster formation.—The thin, platy beds of the Quartermaster occur higher in the formation and are above these "Hackberry and Big Basin" beds. The colors and types of sands and shales in the type Quartermaster area are essentially the same as those in northwestern Oklahoma and in Kansas.

As the terms "Hackberry shale" and "Big Basin sandstone" have priority over the term Quartermaster, it might seem that Quartermaster should be the name dropped. However, according to Kansas literature (16), the name "Hackberry" is preoccupied; and, as this formation is largely shale, "Big Basin" is not a suitable name. Also, as these beds reach their best development in west-central Oklahoma, where the term Quartermaster has long been applied, it seems better to use the term Quartermaster formation and drop the Kansas names.

In Kansas and northwestern Oklahoma, north of Canadian River, the Quartermaster beds immediately above the Day Creek are conformable. At no place in this area has evidence of any unconformity been noticed either at the base of, or within, the Quartermaster.

PERMIAN RED-BEDS AS SERIES OF LENTILS

Much has been said about the Permian Red-beds of western Oklahoma being a series of lentils. Many consider these beds and formations

very difficult to trace accurately and correlate from one area to another. It is true that there are many lenticular beds within these formations and that there are many lateral gradations; but it is also true that there are many lenticular beds and lateral gradations in the non-red Permian and upper Pennsylvanian beds. It is possible to trace these red Permian formations of western Oklahoma through far greater distances than the non-red Permian and Pennsylvanian beds of eastern Oklahoma. For this reason, a few more lentils and a few more lateral gradations can reasonably be expected. The writer considers the contacts between the Permian Red-beds of western Oklahoma to be almost, if not quite, as exact and as possible of accurate demarcation as those of the non-red Permian and upper Pennsylvanian formations of eastern Oklahoma.

CONCLUSION

1. The Blaine formation of northwestern Oklahoma consists of four distinct beds of gypsum, named, in ascending order: Medicine Lodge gypsum member, Shimer gypsum member, Lovedale gypsum member, and Haskew gypsum member. The base of the Medicine Lodge gypsum can be traced as an exact horizon from its northernmost limits in Kansas south to Fairview, Oklahoma, and possibly still farther south.

2. The Dog Creek formation is very closely allied with the Blaine, and westward and southwestward possibly merges with the Blaine to form the thick gypsum formation generally referred to as the Blaine in Texas. However, the Dog Creek is considered as a formation separate from the Blaine in northwestern Oklahoma.

3. The Whitehorse formation consists of three members, namely, Marlow, Rush Springs, and Cloud Chief. Limestones or dolomites occur at two general horizons, namely, the Relay Creek dolomites near the Marlow-Rush Springs contact, and the Weatherford dolomite near the top of the Rush Springs.

The Cloud Chief is removed from its former position as a formation and is placed as a member of the Whitehorse formation, for the reason that beds which are the stratigraphic equivalent of the Cloud Chief were included in the original definition of the Whitehorse. The base of the Cloud Chief is definitely placed as the base of the lowest gypsum bed, which rests on a great thickness of sandstone and above which occurs shale. In northwestern Oklahoma, this basal Cloud Chief bed is the lower gypsum of the so-called double bed. Where these gypsum beds are not present, the base of the Cloud Chief is the contact of shale with the great thickness of sandstone below.

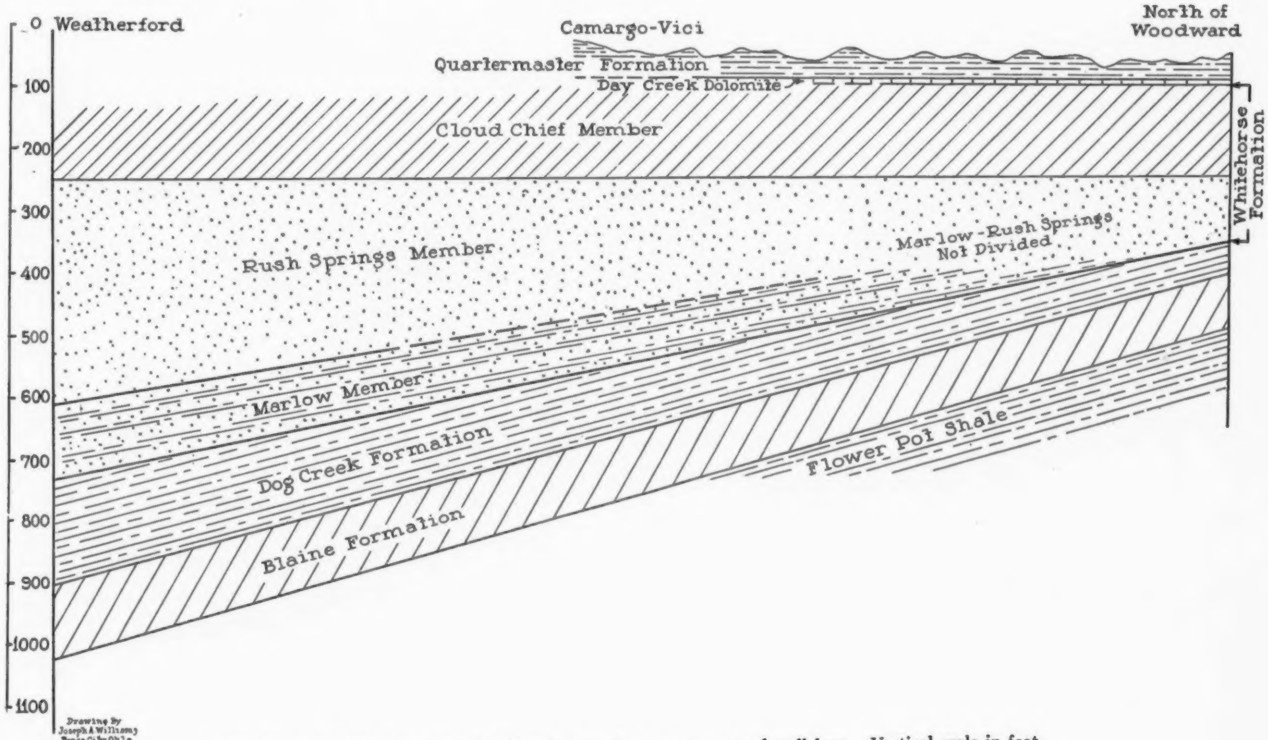

FIG. 8.—Generalized cross section based on surface exposures and well logs. Vertical scale in feet.

4. The Day Creek dolomite includes two beds of dolomite separated by 1-3 feet of red shale. These dolomites are somewhat lenticular or grade laterally into sand or shale. Their horizon can be definitely placed by the sequence of beds and the change from the Whitehorse formation to Quartermaster.

5. All the Permian beds of Oklahoma and Kansas above the Day Creek dolomite belong to the Quartermaster formation. The Kansas terms "Hackberry" and "Big Basin" should be dropped. The writer has not seen beds of gypsum anywhere in the Quartermaster, and suggests that what others have called "gypsum in the Quartermaster" has been so named either as a result of a miscorrelation of the beds, or of the mistaking of calcitic or aragonitic laminae for gypsum.

6. The writer has no reason to think that unconformities occur at the base of, or within, the Whitehorse formation of northwestern Oklahoma. The Quartermaster formation, in northwestern Oklahoma, north of Canadian River, is also considered to be conformable over the Day Creek dolomite.

7. There are lenticular beds and some lateral gradation in the different formations from the Blaine upward, but the contacts between these formations are very near exact horizons and the formations are capable of sharp separation throughout most of western Oklahoma.

BIBLIOGRAPHY

1. Fritz Aurin, "Geology of the Redbeds of Oklahoma," *Oklahoma Geol. Survey Bull. 30* (1917).
2. Clyde M. Becker, "Geology of Caddo and Grady Counties," *Oklahoma Geol. Survey Bull. 40-I* (1927).
3. ———, "Structure and Stratigraphy of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 1 (January, 1930), p. 37.
4. R. L. Clifton, "Woods, Alfalfa, Harper, Major, Woodward, and Ellis Counties, Oklahoma," *Oklahoma Geol. Survey Bull. 40-A* (1926).
5. ———, "Permian Structure and Stratigraphy of Northwestern Oklahoma and Adjacent Areas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 2 (February, 1930), p. 161.
6. F. W. Cragin, "Permian System in Kansas," *Colorado Coll. Studies*, Vol. 6 (1896).
7. Noel Evans, "Stratigraphy of Weatherford Area, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 7 (July, 1928), p. 705.
8. A. J. Freie, "Sedimentation in the Anadarko Basin," *Oklahoma Geol. Survey Bull. 48* (1930).
9. Charles N. Gould, "Geology and Water Resources of Oklahoma," *U. S. Geol. Survey Water Supply Paper 148* (1905).

10. ———, "A New Classification of the Permian Redbeds of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (May-June, 1924), p. 322.
11. Charles N. Gould and Charles E. Decker, "Index to the Stratigraphy of Oklahoma," *Oklahoma Geol. Survey Bull. 35* (1925).
12. Charles N. Gould and John T. Lonsdale, "Geology of Texas County, Oklahoma," *Oklahoma Geol. Survey Bull. 37* (1926).
13. ———, "Geology of Beaver County, Oklahoma," *Oklahoma Geol. Survey Bull. 38* (1926).
14. Charles N. Gould and Frank E. Lewis, "The Permian of Western Oklahoma and the Panhandle of Texas," *Oklahoma Geol. Survey Cir. 13* (1926).
15. A. M. Lloyd and W. C. Thompson, "Correlation of Permian Outcrops on Eastern Side of the West Texas Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), p. 945.
16. R. C. Moore, *Kansas Geol. Survey Bull. 6* (1920), Pt. 2.
17. Roger W. Sawyer, "Areal Geology of a Part of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 3 (May-June, 1924), p. 312.
18. ———, "Kiowa and Washita Counties, Oklahoma," *Oklahoma Geol. Survey Bull. 40-HH* (1929).
19. L. C. Snider, "The Gypsum and Salt of Oklahoma," *Oklahoma Geol. Survey Bull. 11* (1913).
20. C. D. Stephenson, "Observations on the Verden Sandstone of Southwestern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), p. 626.
21. G. G. Suffel, "Dolomites of Western Oklahoma," *Oklahoma Geol. Survey Bull. 49* (1930).

DISCUSSION

H. L. GRILEY, Tulsa, Oklahoma: Mr. Evans has correctly described the relationship which exists in western Oklahoma between the Marlow, Rush Springs, Cloud Chief, and Day Creek units of the Permian section. The critical exposures occur a few miles south of Vici in the valley of a creek tributary to South Canadian River. A section of Permian associated with the Day Creek dolomite lies above ledges of Cloud Chief gypsum. The ledges of gypsum can be traced up stream until they go under cover not more than ½ mile from the outcrop of beds associated with the Day Creek. Only a trace of Day Creek remains beneath Tertiary cover, but the sequence of beds (massive sandstone, calcitic beds, brown shale, semi-concretionary sandstone, et cetera) observed in the underlying 50 feet of section makes possible the identification of the Day Creek horizon. Familiarity with this sequence of beds can be gained from observations made north of Woodward where the dolomite is well developed.

The position of the Day Creek dolomite above Cloud Chief gypsum in exposures in Sections 24 and 25, T. 19 N., R. 20 W., does not seem to be the result of faulting, although faulting of a superficial type does occur in this locality.

In addition to pointing out an occurrence of Day Creek dolomite above Cloud Chief gypsum, Mr. Evans has directed geologists to an exposure in Sec. 18, T. 18 N., R. 19 W., where about 75 feet of section below the base of the Cloud Chief can be studied. Here it can be seen that no beds associated with the Day Creek occur beneath the Cloud Chief, the position formerly assigned the Day Creek.

Some criticism was made in connection with the use of correlations proposed by Mr. Evans because it seemed that such correlations indicated abnormal north dip near Camargo. The supposition of north dip at this point was based in part on computed elevations and the use of intervals. Much of the gypsum of the Cloud Chief pinches out north of Camargo, a natural result of which might be the development of north dip in overlying beds. Structure mapped on beds overlying Cloud Chief gypsum is generally very erratic.

The massive sandstone, the top of which occurs 25-35 feet below the Day Creek dolomite, can be traced throughout a wide area in which the dolomite is absent. This sandstone can be traced, with a reasonable degree of certainty, west in the valley of South Canadian River almost to the Texas line. It is probably the bed which caps a butte located just northeast of the townsite at Cheyenne. A sandstone, occurring at about the same stratigraphic position, is present east of Sayre. In all this area ledges of Cloud Chief gypsum occur below the thick sandstone, and associated with the sandstone there are thin calcitic beds.

SHERWOOD BUCKSTAFF,[1] Oklahoma City, Oklahoma: This discussion of Mr. Evans' paper was originally prepared in July, 1930, by H. F. Schweer and the writer, after the presentation of the paper at Oklahoma City. Before Mr. Evans' revision of his paper was available, Mr. Schweer was already preparing a paper of his own discussing many of these correlations. Consequently, the writer is submitting this discussion alone, with acknowledgments to Mr. Schweer for suggestions.

Mr. Evans' paper is one of the first discussions of northwestern Oklahoma based on detailed field work in an extensive area. It is to be expected that such work would show differences from older work based principally on reconnaissance. Mr. Evans' conclusions are presented clearly and exactly, and are accompanied by the detailed evidence on which they are based. Though the correlations may not all be acceptable, they are all worthy of careful consideration.

Blaine and Dog Creek.—Mr. Evans' discussion of the Blaine formation brings out clearly the fact that the Medicine Lodge and Shimer members as named at present in Oklahoma are mis-correlated with the Medicine Lodge and Shimer as originally named by Cragin in Kansas, and he applies these two names correctly to the two lowest gypsum beds of northwestern Oklahoma. The name Haskew seemingly is applied to a member not previously recognized in the literature, and should be accepted. The so-called Lovedale member is probably the Mangum member as named in Greer County; and the advisability of introducing a new name at this time seems questionable, even though

[1]By permission of the Shell Petroleum Corporation.

Mr. Evans suggests that it may be dropped if necessary. A fifth gypsum bed, called by field men the "alabaster" or "rock-crusher" gypsum, and lying between the Shimer and Medicine Lodge members as defined by Evans, is found in Blaine County. It is probably not present in the area discussed by Mr. Evans, but should be considered in any complete revision of Blaine nomenclature. Mr. Evans ably defends his position in altering certain boundaries of the Blaine while still retaining the original name. His retention of the Dog Creek as a distinct formation is also justified. In northwestern Oklahoma the Dog Creek, the Blaine, and the Flowerpot are all distinct and separable formations. In the Chickasha area, in the deeper parts of the Anadarko basin in subsurface study, and in the Double Mountain group of North Texas, the boundaries of these formations have not been, in many places can not be, exactly identified; and they are combined in the El Reno group, which is correlated as a unit. However, this fact is no reason for abandoning the individual names in areas where they are serviceable.

Whitehorse group.—Mr. Evans' grouping of the Marlow, the Rush Springs, and the Cloud Chief in a single unit (whether it be called *group* or *formation* is immaterial, although the writer believes that the analogy with the El Reno group makes the term *group* preferable) is also a logical step. It has been recognized for some time that the sediments of the Cloud Chief are closely related to the sediments originally named Whitehorse, and the use of a single name to include these units is desirable. If Mr. Evans' hypothesis that the Day Creek is above the Cloud Chief is accepted, the original definition of Whitehorse already includes the Cloud Chief, and Mr. Evans' position is unassailable. Even if this correlation is disproved, the name Whitehorse has been so long applied to these sediments that it seems preferable to alter the original boundaries somewhat rather than to introduce a new name.

Mr. Evans' separation and correlation of the members within this group is open to serious question. The horizon of the double gypsums northeast of Woodward, correlated as the base of the Cloud Chief, is strikingly similar to the horizon of the "Relay Creek" dolomites farther south, which are the base of the Rush Springs. In the Chickasha area, both these dolomites locally change laterally into the basal part of gypsum beds which continue the stratigraphic horizon of the dolomites. The same change is found in the double gypsums of Woodward County. A thin red shale is present in both areas just below the upper dolomite or gypsum. Other lithologic similarities more difficult to describe were noticed by several geologists familiar with the Chickasha area. Mr. Evans correlates the double gypsums northeast of Woodward with certain double gypsums south of Vici, and the latter with accepted Cloud Chief gypsums at Camargo. The writer would not question the correlation from Vici south, but believes that the correlation across the divide separating the North and South Canadian rivers is faulty. The gypsums on the south are very different from those on the north, and are underlain by a different section lithologically. In addition, the intervening intervals do not correspond. The double gypsum north of Woodward is 150 feet below the Day Creek horizon; south of Woodward, only about 50 feet.[1] Consequently this correlation re-

[1]First interval from Mr. Evans' figures; second interval estimated with bank level by several geologists on the recent field trip.

quires the assumption of a considerable north dip not evidenced by any other horizon. It should be noticed that this structural evidence affects only the correlation of the double gypsum across this area, and not the Day Creek. The correlation of the latter across the divide is supported by both structural and lithologic evidence.

Mr. Evans emphasizes the fact that most of the formations in this area thicken southward, and thus accounts for the comparative thinness of the 100 feet of section assigned to the Marlow-Rush Springs; but he neglects the fact that his correlation postulates extensive southward thickening for every member except the Cloud Chief, which remains nearly constant. It is more logical to expect all the members to show southward thickening, and particularly the Cloud Chief, as other evidence indicates that the Anadarko basin was subsiding especially rapidly in later Whitehorse time. The writer believes that the lower 100 feet, called Marlow-Rush Springs, is actually all Marlow; and that the overlying 150 feet should be assigned to the Rush Springs and Cloud Chief, with the strong probability that the Cloud Chief is represented by the zone containing dolomitic stringers, gypsum, and purplish platy beds lying between Mr. Evans' massive sandstone bed and the Day Creek. This correlation would place many of the gypsum ledges of northwestern Oklahoma in the Rush Springs, just as they have been previously correlated. The presence of gypsum lenses in a member which is elsewhere entirely sandstone is in accord with the concept of lateral gradation of clastic sediments to precipitates, as evidenced elsewhere in the Permian basin.

It follows from the preceding correlations that objection should also be made to Mr. Evans' definition of the base of the Cloud Chief, "the base of the lowest gypsum bed which rests on a great thickness of sandstone, and above which occurs shale." A citation is given of Gould's original description of the Cloud Chief, in which shale is described, but no sand. However, the original description of the old "eastern Greer" is ". . . . Chiefly red clay shales, interstratified. . . .with red sandstones and gypsum."[1] The value of defining this contact on the basis of overlying and underlying lithology, in any considerable area, is questionable. The Weatherford dolomite, as noted by Mr. Evans, is in many places overlain by sandstone; but laterally it grades into a gypsum which can be traced north and west of Weatherford for many townships; and in all this area it is considered to be the basal Cloud Chief gypsum, though in its type area it is dolomite. It is probably this same gypsum horizon which Mr. Evans correlates as the base of the Cloud Chief at Camargo. Other unquestionable Cloud Chief gypsums in the Weatherford area are intercalated with sandstones and little or no shale. In northwestern Oklahoma, on the contrary, as previously described, there are many shales in what the writer interprets as Rush Springs. Consequently Mr. Evans' lithologic criteria seem inapplicable. The writer would define the base of the Cloud Chief as the base of the Weatherford gypsum or dolomite in the type area, and its equivalent, when established, elsewhere.

Day Creek dolomite.—Mr. Evans has proved, if his correlation at Camargo of the Day Creek horizon as being above the Cloud Chief gypsums is accepted,

[1] C. N. Gould, *U. S. Geol. Survey Water Supply Paper 148* (1905).

only that the Day Creek is above *lower* Cloud Chief. There are many gypsums in the type area of the Cloud Chief higher stratigraphically than those at Camargo. Consequently, it is still unproved whether the Day Creek is: (1) equivalent to some higher gypsum of the Cloud Chief; (2) equivalent in stratigraphic value to a part or all of the Cloud Chief; (3) above the Cloud Chief, as Mr. Evans assumes.

Quartermaster.—Mr. Evans' correlation of the Hackberry and Big Basin with the Quartermaster is logical, and supported by the lithologic evidence; but its proof depends on his correlation of the Day Creek, which is not yet established.

After the many recent discussions of Permian "lentils" and "unconformities," Mr. Evans' remarks on the subject are timely and pertinent. Lateral gradation, and lithologic lenses, do not make unconformities. Though lithologic units vary and disappear, stratigraphic units, bounded by true stratigraphic horizons, can be traced, not only across northwestern Oklahoma, but across the entire east side of the Permian basin. Mr. Evans' challenge of the outworn ideas of lentils and unconformities is one of the most important contributions of the paper.

NOEL EVANS.—Mr. Buckstaff, in his discussion of the Blaine, calls attention to a fifth bed of gypsum, the so-called "alabaster" or "rock-crusher" gypsum, occurring between the Shimer and Medicine Lodge members. In the drawing showing the core-drill logs accompanying the article, it is shown that the Medicine Lodge member divides and forms two separate beds of gypsum. This explains the fifth bed which Mr. Buckstaff mentions. In this same connection, the other beds or members locally divide to form other separate beds of gypsum. In some localities there are probably as many as seven beds of gypsum in the Blaine; however, in northwestern Oklahoma north of Fairview, there are normally only four beds of gypsum.

Whitehorse formation.—Mr. Buckstaff suggests that the Whitehorse aggregate might better be classed as a *group* than as a *formation*. As he suggests, this is immaterial, but the writer believes that *formation* is better. There seems to be no need to subdivide the units Marlow, Rush Springs, and Cloud Chief, further than to mention beds.

The writer wishes to call special attention to Mr. Buckstaff's discussion of the double gypsums, in connection with correlating this horizon north of Woodward with the Relay Creek[1] dolomites at the top of the Marlow. The writer does not agree with Mr. Buckstaff in his contention that there is a thin red shale associated with these gypsums, north of Woodward, which resembles the thin red shale associated with the Relay Creek dolomites of the Chickasha area. Locally, where the gypsum of this double bed is absent (because of leaching or some other method of removal) there is a thin purplish or reddish zone, generally less than an inch thick. This purplish or reddish zone is composed of calcite and dolomite remnants from the gypsum bed mixed with red

[1]The term "Relay Creek" seems better than "Geary" because in suggesting a new name for the preoccupied term "Greenfield," it seems well to use the same type area if convenient. These dolomites do not occur in good exposures near Geary, and it would be necessary to give locations some distance from Geary.

shale. This zone can not be traced either below or above either of these gypsum beds, but is the remnant of the gypsum, showing conclusively that it is a secondary condition and that it does not represent the red shale bed which in the Chickasha area is associated with the Relay Creek dolomites. On close examination, it is evident that this reddish or purplish zone is not similar to the red shale of the Chickasha area. Mr. Buckstaff says, "The gypsums on the south are very different from those on the north, and are underlain by a different section lithologically." The writer does not agree with this statement. The gypsums on the south seem to have a little greater thickness than those on the north, but even this is arbitrary, depending on specific exposures. In both areas these gypsums are light gray to white with some red. In both areas these gypsums are separated by red shale, and above the higher gypsum of the double gypsums is shale approximately 10 feet or more in thickness. The writer can see no difference between these gypsums of the two areas that would indicate that they might be of different horizons. In both areas, the section below the double gypsums is sand, with no shale or sandy shale, for 100 feet or more. In the north area this sand thickness is 100 feet, and in the south area the thickness exceeds 140 feet. In both areas, the sand immediately below the gypsum is locally gypsum-filled; in other places there seems to be little or no gypsum in the sand. The sand grains in both areas are almost the same in size. In both areas there are gypsum lentils in this sand section below the double gypsums. The writer thinks that there is little or no lithologic difference in the first 100 feet of section below these gypsums.

In all of the area north of Weatherford, there is nowhere a shale bed or any bed which might be called sandy shale in the Rush Springs member. In order to correlate any part of the section above the double gypsums of the north area as belonging to the Rush Springs it would be necessary that the lowest part be mostly shale and that there be approximately 50 per cent shale in any part of the section thus assigned to the Rush Springs. Such a thing would certainly be lithologically different, and in the absence of positive proof would be questionable.

Mr. Buckstaff seems to think that because the lower members thicken southward it would be logical for the Cloud Chief to thicken also. This would be logical, but not necessarily true. In the main article it is pointed out that the Cloud Chief is an exception to this rule and is an exception which can be proved. It can also be said that it is logical to expect a section composed chiefly of shale and gypsum to be more regular in thickness than sections composed of sand or shale alone, or both together. If the present ideas for the depositional conditions for gypsum deposits are correct, it would be expected that such a section would be much farther basinward or farther from a source of shale and sand, and thus less likely to thicken or thin. Attention is called to the Marlow member in the Chickasha area, where it has much gypsum as cementing material in the sands, and one or two beds of gypsum. Also the Blaine is known to cover vast areas with very little depositional thickening or thinning. Mr. Buckstaff suggests that south of Woodward the interval below the Day Creek horizon to the double gypsums is only 50 feet. At the location which he mentions it is possible to observe the beds in vertical section for approximately 50 feet below the Day Creek, and there is nothing like the section

associated with the double gypsums. Furthermore, this is in an area which is complicated by much deep-seated slumping and some superficial faulting. Farther west it is possible to observe beds from the double gypsums upward in vertical section for more than 65 feet, and by correlating the highest gypsum bed in this section across a distance of approximately 1,000 feet, it is possible to see an additional 25 feet of section, and still higher can be seen the massive sand, the top of which occurs 25-30 feet below the Day Creek. This location is near the northeast corner of Sec. 19, T. 17 N., R. 24 W. Similar sections, but less well exposed, occur 10 or 15 miles west of Camargo, and parts of the section just above the double gypsums may be seen in many places in the vicinity of Camargo. In all exposures this section is remarkably similar to that of the north area above the double gypsums. In the south area there is some more gypsum and less sand, but in both areas it is notably a section of shale, sand, and gypsum, with the shale the most notable of these. In both areas the total thickness of this section (Cloud Chief) is approximately 150 feet.

Mr. Buckstaff questions the soundness of correlating and defining the lower contact of the Cloud Chief on the basis of overlying and underlying lithology. This basis, together with any traceable beds which may occur, seems to the writer the only sound method. As stated by Mr. Buckstaff, the Weatherford dolomite and gypsum can be traced for many miles. The gypsum approximately 20 feet below the base of the double gypsums in the cliff a mile or more northeast of Camargo is correlated with the Weatherford by many geologists, including the writer, who have worked in the area from Weatherford northward. The writer has always considered the base of the Cloud Chief in the Weatherford area to be approximately 60 feet above the Weatherford dolomite or gypsum, because this interval is sand with a few gypsum lentils, the sand being in all respects similar to that underlying the Weatherford. Associated with the gypsums above this sand zone are shale and some sand, but below the lowest of these higher and more massive ledges of gypsum there is no shale. The correlation of the base of the Cloud Chief, on the basis of sand and shale, can be definitely made from the lowest parts of the Anadarko basin northward across northwestern Oklahoma and still farther into the Panhandle of Oklahoma. This basis is the only one on which such a widespread correlation can be made, but, on this basis, it can be made accurately.

BACTERIAL GENESIS OF HYDROCARBONS FROM FATTY ACIDS[1]

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ABSTRACT

It has been generally accepted that petroleum has originated from animal and plant remains—particularly from fats, oils, waxes, and resins—these substances being relatively resistant to decay. However, they are readily hydrolyzed in nature into their components, that is, fatty acids and an alcohol, especially glycerol. The course of decomposition of glycerol is well known, but of the fatty acids, the decomposition of acetic acid only has been extensively studied. It is decomposed under anaerobic conditions by the methane bacteria to carbon dioxide and methane.

In the present paper the writer is concerned with the hypothesis that the higher homologues of the series might be decomposed by the same group of bacteria to carbon dioxide and the corresponding hydrocarbon. Results of experiments show that this is not the fact, but that all the fatty acids studied, from acetic to margaric, give rise to carbon dioxide and methane only.

INTRODUCTION

Ever since petroleum began to be of interest to man, many and varied theories have been advanced to explain its origin. Some of these hypotheses have been without experimental foundation, others have been more or less supported by laboratory work; none has been conclusively proved because of two difficulties: (1) the certain designation of the source bed and material ordinarily has been impossible, and (2) it has been widely assumed that conditions now are not the same as those prevailing at the time the oil was formed; therefore, the observation of the process has been considered impossible.

[1]This paper contains preliminary results obtained in an investigation on "Diatoms as a Source of Oil," listed as Project No. 5 of the American Petroleum Institute research program. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by the Universal Oil Products Company. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council. Read before the Pacific Section of the Association at the Los Angeles meeting, November 6, 1930. Manuscript received, January 8, 1931.

[2]American Petroleum Institute research fellow, Jacques Loeb Laboratory, Hopkins Marine Station, Stanford University. Introduced by W. S. W. Kew.

In some of the California oil fields, however, the evidence is overwhelming that the extensive diatomaceous deposits represent the source beds, the supposed source material being the organic matter of the diatoms.[1] Assuming this designation of the source material to be correct, the second difficulty in the way of proving the origin of California petroleum from diatoms seemed to have been mitigated when H. C. McMillin, of the United States Fisheries Bureau, called to the attention of C. F. Tolman and L. B. Becking, of Stanford University, the fact that immense quantities of diatoms are produced annually on the beaches north of the mouth of Columbia River in Washington, and that collection of large quantities for extraction of the oil would not be difficult.[2] The opportunity was thus afforded for a chemical investigation of the character of the oil and its transformations under conditions of marine sedimentation probably not very different from those prevailing at the time the oil-producing strata were deposited.

The material extracted from the diatoms by petroleum ether amounted to about 4.5 per cent of the dry weight, and had the following composition.[3]

		Per Cent
Pigments (chlorophyll, carotin, phycoxanthin)		43
Fatty substances		52
Solid fat	17	
Fatty acids	35	
Phytosterols		3
Hydrocarbons (long chain, unsaturated)		2
		100

The fatty fraction is of essentially the same type as the oil from any other vegetable or animal source. It is a mixture of compounds whose principal difference from petroleum hydrocarbons is that they contain oxygen.

Because of this similarity to fats and oils from other sources, the problem of explaining the transformation of diatom oil to petroleum is no different from that faced by every investigator who has regarded petroleum as derived from fats and oils of organic origin. Briefly, it is necessary to find a means of freeing the source material of oxygen, while

[1] F. M. Anderson, *Bull. Geol. Soc. Amer.*, Vol. 37 (1926), p. 585. C. F. Tolman, *Econ. Geol.*, Vol. 22 (1927), p. 454.

[2] L. B. Becking, C. F. Tolman, H. C. McMillin, *et al.*, *Econ. Geol.*, Vol. 22 (1927), p. 356.

[3] T. Hashimoto, unpublished data obtained in connection with American Petroleum Institute Project No. 5, entitled "Diatoms as a Source of Oil."

preserving the optical activity which is the chief criterion of organic origin.

Such a transformation can be accomplished in the laboratory by a process of destructive distillation, and such a process in nature is postulated by the widely accepted Engler-Höfer theory of the origin of petroleum.[1] That this sort of process would not necessarily destroy optical activity was demonstrated by Neuberg,[2] who derived an optically active petroleum-like substance from optically active fatty acids by subjecting them to destructive distillation. His optically active fatty acids were derived from proteins by bacterial decomposition.

In the California oil fields, however, the temperatures and pressures in the diatomaceous deposits have not, according to Tolman,[3] been great enough to account for such a process, judging by the form in which the siliceous tests of the diatoms have been preserved. If this is so, it is necessary to attempt to account for the transformation on the basis of the activity of agents capable of working at low temperatures. The only known agents which act at low temperatures and which also give rise to optically active compounds are biological in nature.

Moreover, there is good evidence that such agents might have been associated with the deposition of petroleum. The oil is commonly associated with marine sediments; water found in oil wells is similar in character to sea water; the sulphate-reducing bacteria found everywhere in the black mud of the ocean floor have also been found in these waters.[4] This latter observation, especially, shows that the conditions under which the oil is now found are such that life can exist there now, and presumably has existed since the beds were deposited. Whether the latter assumption is true or not, the fact that the source beds are marine deposits of organic sediments has as a corollary the fact that organic matter in nature is invariably accompanied by a more or less specific flora capable of deriving energy from, and so transforming it by means of, decomposition processes. Even in those oil fields where the lifeless forces of high temperatures and pressures have been sufficient in themselves to account for the transformation of the source material into

[1] C. Engler u. H. v. Höfer, *Das Erdöl*, Bd. II (1909), p. 59.

[2] C. Neuberg, *Biochem. Zeit.*, Vol. 1 (1906), p. 368.

[3] C. F. Tolman, *op. cit.*

[4] Edson S. Bastin, *Science*, Vol. 63 (1926), p. 21; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 1270.
Murray Stuart, *The Geology of Oil, Oil-Shale and Coal* (1926), pp. 1-100.

petroleum, it is useless to reckon without taking into consideration the changes brought about by living agents *before* the material was subjected to high temperatures and high pressures, for biological action is much more rapid than geologic. In this connection we refer again to Neuberg's hypothesis that the optically active fatty acids have been derived from proteins by bacterial action. We may also recall that Engler and Höfer have postulated that the protein parts of organisms are destroyed by bacteria, leaving the fats and oils to be acted upon by destructive distillation.

But why are not the fats and oils themselves destroyed by bacteria, either completely decomposed, or partly decomposed in such a way that one of their products is hydrocarbon in nature? It is true that fats and oils are more resistant to bacterial action than proteins and at least the simpler carbohydrates, probably because they are attacked by fewer and more specific organisms; but they *are* subject to bacterial decomposition.

To recapitulate: if the assumption that the source material was organic matter is correct, it is certain that biological agents capable of transforming that material were able to thrive. As we have no reason to believe that bacteria existent now are greatly different from their progenitors, we may be justified in the search for microbial processes which lead to the formation from fatty materials of hydrocarbons such as are found in natural petroleum.

In this connection the experiments of E. McKenzie Taylor should be mentioned.[1] Taylor showed that fats and oils, mixed with sand and covered with a layer of clay in a beaker at room temperature, soon produced gas in sufficient quantity to lift the clay roof from the sand. The gas consisted mainly of methane. Taylor also mentions that in experimenting with tributyrine a mixture of gaseous paraffins is produced; triacetine is decomposed with the production of methane only.

Although from these experiments Taylor concluded that "it appears that the fat is hydrolyzed, the resulting glycerol being converted into methane, and the fatty acid being reduced to the corresponding paraffin," this conclusion must be considered incorrect, for if the fatty acids were reduced to the "corresponding paraffin," the decomposition of triacetin should have resulted in the formation of ethane instead of methane, whereas the latter compound was found.

[1]E. McKenzie Taylor, *Nature,* Vol. 120 (1927), p. 448; *ibid.,* Vol. 121 (1928), pp. 789, 940.

From these considerations it is evident that the anaerobic decomposition of oils and fats becomes a very important object for investigation. Since oils and fats are hydrolyzed before being subject to further decomposition, and glycerin under anaerobic conditions is known to lead to the production of fatty acids in addition to carbon dioxide and hydrogen,[1] our main attention has been focused on the anaerobic decomposition of the fatty acids.

PREVIOUS EXPERIMENTS

Our knowledge of these fermentation processes is very limited. Up to the time these experiments were begun, the only important investigations reported had been made by Söhngen in 1906[2] and by Coolhaas in 1927.[3] Very recently Buswell and Neave have published the results of similar experiments.[4]

Söhngen's experiments showed that in an otherwise purely mineral medium, formates, acetates, and normal butyrates were quantitatively decomposed into methane and carbon dioxide, and strong indications were obtained that the decomposition of capronates, caprylates, and caprinates followed the same lines. This investigator was led to the conclusion that only the salts of the even-numbered fatty acids with a straight carbon chain were subject to decomposition, whereas the odd-numbered acids and all those fatty acids with a branched carbon chain were not attacked. Formic acid was the only exception.

Coolhaas, working with thermophylic organisms, later established the methane fermentation of formates, acetates, and iso-butyrates; all the other fatty acids tried, including *n*-butyric acid, gave inconclusive or entirely negative results.

The fermentation of acetates with the production of methane and carbon dioxide suggests that this process might be represented as a decarboxylation.

[1]H. R. Braak, "Onderzoekingen over vergisting van glycerine," dissertation at Groningen (1928), pp. 1-229.

[2]N. L. Söhngen, "Het ontstaan en verdwijnen van waterstof en methaan onder den invloed van het organische leven," dissertation at Delft (1906), pp. 1-140.

[3]C. Coolhaas, "Bijdrage tot de kennis der dissimilatie ven vetzure zouten en koolhydraten door thermophiele bacterien," dissertation at Wageningen (1927), pp. 1-140. Also in *Centralblaat Bakt. Parasitenk.*, Abt. II, Vol. 75 (1928), p. 161.

[4]S. L. Neave and A. M. Buswell, "Chemical Studies on Sludge Digestion," *Ohio State Water Survey Circular 8* (1930); *Jour. Amer. Chem. Soc.*, Vol. 52 (1930), p. 3308; A. M. Buswell, *Ind. Eng. Chem.*, Vol. 22 (1930), p. 1168.

$$\begin{array}{lllllll}
CH_3 & & H] & CH_4 & & & \\
\vert & & \vert & & & & \\
COO & & OH & HOCOO & & & \\
& \diagdown & & & \diagdown & & \\
& & Ca\ + & = & & Ca & = 2\,CH_4 + CO_2 + CaCO_3 + H_2O \\
& \diagup & & & \diagup & & \\
COO & & OH & HOCOO & & & \\
\vert & & \vert & & & & \\
CH_3 & & H & CH_4 & & &
\end{array}$$

If the anaerobic decomposition of fatty acids could actually be represented by this scheme, the higher fatty acids should give rise to the formation of the corresponding higher hydrocarbons.[1]

$$\begin{array}{lllllll}
R & & H & & & & \\
\vert & & \vert & & & & \\
COOMe & + & OH & = & RH & + & HOCOOMe \\
\text{Fatty acid salt} & & & & \text{Hydrocarbon} & & \text{Bicarbonate}
\end{array}$$

Assuming the asymmetric carbon atom to be other than the alpha atom, the resulting hydrocarbons would be optically active if derived from optically active material.

It is true that Söhngen's data on the fermentation of butyrates, capronates, caprylates, and caprinates, as well as Coolhaas's experiments on isobutyrates, did not seem to substantiate this theory.[2] However, a renewed attack on this problem was not at all superfluous in view of the fact that differences had already been established between fermentations carried out at 30° C. and those at 60° C. The occurrence of a typical decarboxylation would also have given a satisfactory explanation of the results obtained by McKenzie Taylor.

[1]This suggestion was first made by G. Meyer in 1906 (*Chem. Zeit.*, Vol. 30, 1906, p. 814) seemingly on the basis of his own experiments. He writes: "Wenn man bedenkt, dass essigsaure Salze bei der Kloakenfäulnis in Methan und Kohlensäure zerlegt werden, so liegt es nahe, zu vermuten, dass das Erdöl durch solche Gärung aus Fetten oder fettsauren Salzen entstanden war....Die Annahme, dass das Erdöl durch hohen Druck oder hohe Temperatur aus den Fetten gespalten wird, scheint mir mehr den Laboratoriums—als den naturlichen Verhältnissen zu entsprechen."

[2]The experiments of Neave and Buswell with formic, acetic, propionic, *n*-butyric, and *n*-valeric acids, as well as with crude fat mixtures, demonstrate conclusively that higher hydrocarbons are not to be expected from such fermentations, but, as their experiments were contemporary with those of the writer, their results came to his attention after the described experiments were finished.

EXPERIMENTAL

DEVELOPMENT OF FERMENTATION

The experiments were made in the following way. Enrichment cultures were made from river mud, littoral marine mud, and deep sea mud, using media with tap or sea water with the addition of 0.5 per cent dipotassium phosphate, 0.1 per cent ammonium sulphate, and 0.5-2.0 per cent of calcium acetate or of the sodium salt of one of the following fatty acids: propionic, *n*-butyric, *i*-butyric, *n*-valeric, *i*-valeric, *n*-caproic, *i*-caproic, heptylic, lauric, palmitic, margaric, and stearic.[1]

The medium was made up without the organic salts and boiled to drive off the dissolved air. It was then transferred to sterile glass-stoppered bottles, the soap added, and the bottle placed in the incubator to cool. Mud was then added and the cultures returned to the 30° C. incubator.

In all experiments the first change to be observed was the formation of "black mud," caused by the growth of sulphate-reducing bacteria. In the calcium acetate cultures, gas began to be evolved within two or three days at 30° C.; and in a few cultures placed at 50° C., fermentation began within 24 hours. Cultures of the other acids developed more slowly, requiring an incubation period ranging from a week or two to three or four months. Butyrate cultures produced gas next after the acetate cultures, being followed irregularly by the others, except that no gaseous fermentation developed in the heptylate and laurate cultures when these were inoculated with fresh water and littoral marine muds. In the

[1]A word as to the purpose and use of enrichment cultures may not be amiss. Medical and industrial bacteriologists use "pure cultures" of one organism almost exclusively, culturing that organism on various organic substances as a food or energy source, thereby determining whether or not the organism can use a particular substance, and if so, what transformations of that substance will result.

Applied to problems regarding the transformations of material in nature, this method yields results of little value, because the fact that an organism can produce a certain transformation of a given food substance when not in competition with other organisms does not necessarily mean that in nature it will be of even minor importance in causing the destruction of that particular organic material. Many other organisms may also be able to make use of that food, and more advantageously. Hence, in nature, the organisms that make the best use of the food are the organisms that come to the fore.

To "catch" these organisms Winogradsky has developed the method of enrichment cultures, which consists of making a culture containing the food substance whose transformations in nature are to be studied, and inoculating it with mud or soil. It has been shown that it is not unreasonable to expect to obtain all possible organisms out of a relatively small inoculum; hence, all organisms capable of competing for the use of the particular food, and so likely to be important in nature, will appear, can be isolated, and their metabolic activities studied. Thus, by means of the technique described, the writer intended that all organisms important in the transformation of fatty acids in nature should show their influence.

palmitic and margaric acids, the evolution of gas became so rapid that large quantities of the culture liquid were expelled with the gas.

The series in which deep sea mud was used as an inoculum was started later than the other two. When inoculated with this mud the heptylate culture developed a rapid fermentation, and finally the laurate culture also produced gas.

As most of these cultures developed very slowly, experiments were made in order to determine whether the development could be made to occur more rapidly at a different *pH*.[1] However, the experiments on the influence of the *pH* of the medium have not yet given conclusive results.

In these experiments the medium with calcium acetate was used. This medium when prepared as already outlined has a *pH* near 7.0. A series of calcium acetate cultures was prepared and the *pH* adjusted by means of dilute hydrochloric acid or sodium hydroxide to *pH*'s 5.0, 6.0, 7.0, 8.0, and 9.0. The series was inoculated from an active acetate culture. Although the cultures at a *pH* of 5.0 and 7.0 developed first, there was no difference in the final activity of the five cultures. The observed difference in time of development can also be explained on the basis of differences in the amount of inoculum used.

An enrichment culture was made with calcium acetate and inoculated from a natural concentrate found near the laboratory, containing about 6 per cent $NaCl$ and having an alkalinity of about $0.1N$, caused by carbonates. Although development was slow, after several months a rapid fermentation occurred even in this alkaline solution.

On the contrary, when the *pH* of thirty cultures (cultures of each of the thirteen acids were included) was tested, it was found that nearly

[1] *pH* is defined as the logarithm of the reciprocal of the concentration of hydrogen ions, or in the ordinary notation

$$pH = \log \frac{1}{[H+]}$$

Inasmuch as in a water solution the product of the concentrations of hydrogen and hydroxyl ions is equal to a constant (1×10^{-14}), all degrees of acidity and alkalinity can be expressed in terms of the concentration of hydrogen ions. For example, in a neutral solution the concentrations of hydrogen and hydroxyl ions are equal and the *pH* is 7.0. Acid solutions have a *pH* below 7.0, and alkaline solutions, a *pH* above 7.0.

Whereas the "total" or "titratable" or "potential" acidity is a measure of the quantity of hydrogen which can be made to ionize by the addition of a base, the *pH* is a measure of the number of hydrogen ions actually present in a given system at a given time. Living organisms are, as a rule, insensitive to the total acidity or alkalinity, but their possibility of growth is often very sharply limited by the concentration of hydrogen ions, which concentration is expressed by *pH*.

For further details, refer to W. Mansfield Clark, *The Determination of Hydrogen Ions*, third edition (Williams and Wilkins, 1928).

all were alkaline in reaction, and that the most active cultures had the lower *pH*'s. All of the cultures had been very active. To one series dilute hydrochloric acid was added to lower the *pH* to about 6.5. A large quantity of gas (carbon dioxide) was evolved upon the addition of the acid, and practically all of the members of the series became active again within 2 or 3 days. The indication here obtained that active fermentation was inhibited by increasing *pH* is in accord with the experience of Neave and Buswell, who found it advantageous to use the calcium salts of the acids, or to add part of the fatty acid free instead of as a salt. It should be noted that in the writer's experiments most of the cultures were prepared with sodium salts, whereas the calcium salt of acetic acid was used in the cultures of the experiment on the influence of *pH*. During the fermentation the fatty acid salt is decomposed with the production of carbonates; therefore, it is obvious that the decomposition of the sodium salt, leading to sodium carbonate, tends to produce markedly higher alkalinities than the decomposition of the calcium salts.

Concerning the influence of another factor we have at present insufficient knowledge. This is the sediment. Cultures which contain some sediment at the bottom are without exception much more active than those which do not contain sediment—indeed, it may almost be said that there is no fermentation of this type without sediment. Cultures containing a large amount of sediment are also more easily transferred than those containing principally liquid.[1] The function of the sediment is not quite clear; the most probable explanation of its influence is that it provides in its cavities for the completely anaerobic conditions required by these organisms. It must be borne in mind that even the most carefully prepared anaerobic cultures contain minute traces of oxygen. The chemical nature of the sediment is without influence on its function; calcium carbonate, boiled kieselguhr, or fine sand may be used with good results.

An adequate description of the causal organisms of these fermentations can not be made at this time, as pure cultures have not yet been obtained. Söhngen and Coolhaas likewise did not succeed in isolating the methane-producing bacteria in pure culture. The development of the enrichment cultures might suggest that the production of methane is due to the sulphate-reducing bacteria, for before any active fermentation becomes apparent there is always a profuse development of black mud. That this development of the sulphate-reducing bacteria occurs at the expense of the fatty acid can be conclusively demonstrated by

[1]Compare in this respect also C. Coolhaas (*op. cit.*), who came to the same conclusions.

inoculating with mud two cultures, one with, and one without, the fatty acid salt. In the former culture, only, the production of hydrogen sulphide becomes apparent.

On the contrary, after many transfers, an actively fermenting culture may be obtained which contains only a white sediment; moreover, inoculations from nearly pure cultures of sulphate-reducers on fatty acids do not cause the production of methane. Finally, the organisms present in actively fermenting cultures are not at all of the typical shape of the sulphate-reducing bacteria. The latter are spirilli or vibrios, whereas Söhngen's methane-producing cultures contained a sarcina and a rod form. Therefore, it is very probable that we are here concerned with bacteria of two distinct groups.

Nevertheless, the transformations of fatty acids, oils, and fats caused by sulphate reducers are worth further investigation as being active factors in nature in the decomposition of oils and fats,[1] and certainly not less because of the interesting speculations of Murray Stuart[2] on their relations to the origin of petroleum.

Baars[3] has recently attempted to clarify the decomposition of fatty acids by sulphate reducers by growing pure cultures of these bacteria on media containing a fatty acid as the sole source of energy. The fatty acids were found to be completely oxidized, the products of the reaction being carbon dioxide and hydrogen sulphide. No methane was produced. In all these experiments the sulphate was present in excess, so that a possible function of organic matter as a hydrogen acceptor could not be established. However, in his experiments with sulphate-free media, the bacteria did not develop. These experiments still leave undetermined the possibility of the reduction of organic compounds by an active growth of sulphate reducers after all the available sulphate has been reduced so that the organism must either use some other substance as a hydrogen acceptor, or cease growing.

That the methane-producing organisms attacking the various fatty acids are at least different strains is evidenced by the large difference in time required for the development of active fermentation on different acids; and still more by the fact that heptylates and laurates were induced to ferment only after inoculation with deep sea mud. Also the

[1]G. Seliber, *Comptes Rendus, Soc. Biol.*, Vol. 99 (1928), p. 544.

[2]Murray Stuart, *op. cit.*

[3]J. K. Baars, "Over sulfaatreductie Door Bacterien," dissertation at Delft (1930), pp. 144-54.

fact that Söhngen did not succeed in obtaining actively fermenting cultures of the odd-numbered fatty acids after inoculation of these media with active acetate or butyrate cultures (which fact was confirmed by the writer's experience) substantiates the idea that different types (species) have to be distinguished. The extremely slow development of most of these cultures makes it difficult to obtain cultures sufficiently pure for carrying out more decisive experiments without the expenditure of a considerable amount of time. Without pure cultures this question can not be definitely answered.

FERMENTATION PRODUCTS

The gas produced during the fermentation of the various fatty acids was collected over mercury by substituting a rubber stopper carrying an S-shaped capillary for the glass stopper. No attempt was made to expel completely the readily soluble carbon dioxide and hydrogen sulphide from the culture liquid. These two gases were absorbed together in KOH solution, after which the absence of hydrogen in the remaining gas sample was established either by passing the gas over palladium asbestos at 100° C. to absorb the hydrogen, or by passing a mixture of the gas with air over palladium asbestos catalyst at 350° C. Under the latter conditions the oxidation of hydrogen is complete, whereas the methane present does not enter into reaction with the oxygen.

The remainder of the sample was finally divided into several parts and analysis completed by exploding each part with oxygen, after which the quantities of carbon dioxide formed and oxygen consumed were determined. From these data the formula of the combustible gas was calculated.

So collected and analyzed, the gaseous products of the fermentation of all of the aforementioned fatty acids were found to be carbon dioxide (and hydrogen sulphide), methane, and a small amount of inert gas. The calculated formula for the combustible part of the gas was in agreement with that of methane within the experimental limits in all analyses made. It must be considered proved, therefore, that *the anaerobic decomposition of saturated fatty acids by bacteria of the methane-producing type leads to the production of methane as the only hydrocarbon.*

As Table I shows, the proportion of the different constituents varies somewhat. In general, it can be said that the gas consists of 15-25 per cent carbon dioxide and hydrogen sulphide, 60-70 per cent methane, and 5-15 per cent of inert gas. The gas derived from acetate and *n*-capronate cultures differs from this generalization, having a higher amount

of carbon dioxide and hydrogen sulphide (30 per cent), and a lower proportion of methane (55-60 per cent); while the gas derived from propionate differs in the other direction, having less carbon dioxide (7 per cent) and more methane (80 per cent).

It is obvious that the variation in composition of the gas is not related in an orderly way to the structure of the molecule as considered from the standpoint of size, odd or even numbers of carbon atoms, or straight or branched chains. This must be partly the result of a simultaneous occurrence of different types of decomposition (the sulphate reduction and the methane fermentation), partly also of the fact that the quantity of carbon dioxide liberated by the methane fermentation is not entirely collected, for Neave and Buswell, who took pains to collect all the carbon dioxide produced in their experiments, have felt justified in postulating a general formula for the fermentation.

$$C_nH_{2n}O_2 + \frac{(n-2)}{2} H_2O = \frac{(n+2)}{4} CO_2 + \frac{(3n-2)}{4} CH_4$$

Therefore, the figures in the table are of importance only in that they show that methane is the only hydrocarbon produced by this type of decomposition from all of the fatty acids investigated. All of these data unite to show that the methane fermentation can not be considered a simple decarboxylation process, nor was Söhngen's original explanation, involving fermentation of the even-numbered fatty acids only, correct, as the odd-numbered acids and those with branched chains also have been shown to be subject to fermentation.

The nature of the gas fraction indicated as inert or incombustible has not been studied. The fact that upon purification of the culture by repeated transfers this fraction decreases makes it seem doubtful whether it is a product of the methane-producing bacteria, especially as Söhngen's, Coolhaas's, and Neave and Buswell's experiments all show that a culture of bacteria producing methane fermentation after purification by repeated transfers does not produce any gaseous compounds other than methane and carbon dioxide.

Although there was no indication that any products other than carbon dioxide, hydrogen sulphide, carbonates, and methane had been produced, the remaining liquid in the culture bottles was finally extracted with ether after the liquid had been boiled with *KOH*. In not a single experiment was there any determinable quantity of unsaponifiable residue left after evaporation of the ether.

SUMMARY

Acetic, propionic, *n*-butyric, *i*-butyric, *n*-valeric, *i*-valeric, *n*-caproic, *i*-caproic, heptylic, lauric, palmitic, margaric, and stearic acids are decomposed to carbon dioxide and methane by anaerobic organisms occurring both in fresh-water and in marine muds.

The origin of the higher hydrocarbons is not to be sought in the action of organisms of the methane-producing type on saturated fatty acids.

It should be pointed out, however, that this negative result in experimenting with saturated fatty acids does not exhaust the possibilities for the origin of petroleum from diatoms. There still remain the undetermined possibilities that the decomposition of the unsaturated fatty acids may follow a course different from that followed by the decomposition of the saturated compounds (though this does not seem probable); that in the absence of sufficient sulphate, the sulphate-reducing bacteria may be able to reduce the fatty acids, and indeed other organic matter; and finally, that the anaerobic decomposition of the pigments, which are largely hydrocarbon in nature, may lead to the formation of petroleum-like compounds. Concerning this third possibility nothing is known to date.

TABLE I

COMPOSITION OF GAS PRODUCED BY FERMENTATION OF FATTY ACIDS

Acid	*CO_2 and H_2S*	*CH_4*	*Incombustible*
Acetic	30.5	56.9	12.6
	30.8	59.6	9.6
	30.6	60.5	8.9
	29.5	64.6	5.9
Propionic	7.1	82.5	10.4
n-Butyric	18.0	71.1	10.9
	18.2	64.3	17.5
i-Butyric	20.4		
n-Valeric	18.4	69.9	11.7
i-Valeric	17.4	62.6	20.0
	16.8	75.4	7.8
n-Caproic	29.0	60.1	10.9
i-Caproic	13.0	76.1	10.9
	15.9		
Heptylic	19.8	64.6	15.6
Lauric	23.4	67.9	8.7
Palmitic	18.0	68.1	13.9
	22.8	72.0	5.2
Margaric	23.6	70.4	6.0
	21.2	73.2	5.6
Stearic	14.0	69.3	16.7

EFFECTS OF UNDERGROUND STORAGE CONDITIONS ON CHARACTERISTICS OF PETROLEUM[1]

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ABSTRACT

This paper describes certain effects which may be produced on crude petroleum during migration or storage by contact with oxidizing agents and sulphur, by fractional distillation and divided migration of the products, by percolation through beds of adsorptive solids, and by possible subjection to cracking temperatures under pressure. The wholly theoretical conclusions reached are based on a debatable assumption of migration during long time periods and, being theoretical, are set forth as processes which might occur under suitable conditions and are not urged in regard to any specific deposit.

The purpose of the writer is to present, as briefly as may be, an outline of the conditions which may influence the characteristics of a petroleum during its formation and while it is in underground storage, and of the nature of the changes which may result from a change of environment.

The origin of petroleum is a subject which one may discuss indefinitely without arriving at any certain conclusion. The writer is old-fashioned enough to believe that most petroleum has been formed by the destructive distillation of animal fats and of fossilized vegetable matter. He considers it also very probable that vegetation widely disseminated in sedimentary strata, and not necessarily nor ordinarily occurring in such accumulated masses as coal or lignite beds, has been the source of most petroleum. Such highly diffused woody and resinous remains would be subject to destruction at extremely low temperatures, would leave no visible carbonaceous residue, and might be carried by flowing underground water or by repeated vaporizations to points of accumulation far distant from the point of origin.

The writer visualizes this destructive distillation as occurring during the subsidence of sedimentary strata into zones of higher temperature. During such subsidence the vaporized product would move upward

[1]Read before the Pacific Section of the Association, Los Angeles meeting, November 7, 1930. Manuscript received, November 7, 1930.

[2]General Petroleum Corporation, Higgins Building. Introduced by C. M. Wagner.

through the subsiding strata and would thus gradually increase in quantity at some isothermic level, relatively close to the earth's surface, at which the temperature would permit it to assume a liquid condition. During an ample period of time and repeated oscillations of petroleum-containing strata, such distillation and condensation might be many times repeated.

The products of such distillation of organic matter, which is probably fossilized to a condition analogous to that of coal or lignite, would be a petroleum rather than a tar-like body because of the extreme slowness and the consequent low temperature at which it would occur. The so-called low-temperature distillation of coal now commercially practiced gives a product intermediate between petroleum and coal-tar in its characteristics and this variation toward petroleum is caused solely by increasing the time and reducing the temperature of distillation.

The time which is available for a commercial operation is, of course, a matter of hours, but during the gradual subsidence of strata containing organic remains, the distillation period is enormously increased, temperature is raised by the most gradual increments, and the local superheating which tends to produce the aromatic compounds found in low-temperature tars is entirely eliminated.

The statement may appear radical, but the writer is firmly convinced that the differences between such typical crudes as the paraffine or aliphatic oils of Pennsylvania, the naphthenic and asphaltic oils of California, the naphthenic non-asphaltic oils of Russia, and highly aromatic oils such as those of the Santa Maria field, are the result of temperature and pressure conditions under which they were formed or to which they have since been subjected rather than of the class of organic remains from which they were produced, except in so far as the nature of the raw material may affect the hydrogen-carbon relation.

The origin of petroleum may seem to be irrelevant to the subject of this paper, but in the writer's opinion it is not, because the environmental conditions which produce petroleum are exactly the conditions which may, at a later time, bring about profound and repeated changes in its characteristics. The ordinary concept of petroleum is that of a heterogeneous and highly variable mixture of a great many chemical individuals, that is, of gases, light and heavy hydrocarbons, solids in the form of paraffine and asphalt, acids, and basic bodies. This is a true picture of any petroleum as it is withdrawn from the ground and taken to the laboratory or to the refinery. We can separate the solid paraffines and by appropriate treatment fractionate them into chemical individuals.

We may separate the fixed gas and at least approximately determine its constituents. We can separate the volatile part of the crude and by repeated fractional distillation obtain bodies of constant boiling point to which a definite molecular weight and structure may be ascribed. When, however, we attempt to separate from each other the liquids constituting the lubricating fraction of the crude, we find that the products of fractional distillation are extremely variable with very slight changes in technique and it is obvious that the bodies yielded by these fractionations are not the bodies originally contained in the crude, but are substances resulting from the decomposition and rearrangement of these heavier parts. In other words we can not, by any known laboratory manipulation, maintain the original arrangement of the hydrogen and carbon atoms during the separation of the higher-boiling constituents of the oil.

The proper concept of a petroleum in underground storage, subject to variable temperature and pressure and to enormously extended surface contact with solids capable of acting as catalysts, is that of an accumulation consisting substantially of carbon and hydrogen, with smaller and entirely incidental quantities of nitrogen, sulphur, and oxygen, this accumulation being in a condition of stability only so long as its environment is constant. In other words, this accumulation of carbon and hydrogen is ready to respond and does respond to changes in environment by changes in its structural arrangement and it is possible for these changes to take either direction as regards the relative proportions of light and heavy constituents, the relative proportion of gas to liquid, and the preponderance in quantity of one or another of the main groups of hydrocarbon.

The classic bomb experiments of Stillman are a vivid illustration and a substantial proof of the mutability of the ultimate hydrogen and carbon constituents of mixed hydrocarbons. Stillman placed in a sealed bomb various fractions of Pennsylvania crude oil, these fractions including heavy lubricating residues, volatile top cuts, purified paraffine, rod wax, and vaseline. Allowing a certain fixed proportion of unoccupied capacity in the bomb, sealing it, heating to a predetermined temperature, and cooling, he obtained as a final product in each case a mixture of liquids comparable with the crude oil from which the fractions were obtained and containing, so far as could be determined, all the constituents of the crude, the proportions of these constituents varying to some extent with the percentage relation between carbon and hydrogen in each raw material. By varying the amount of outage and the tem-

perature, a variation in the composition of the final product could be made, though in each experiment almost all the constituents of a crude were present. In other words, at the temperature and under the pressure which he reached in his bomb, the original material seems to have been completely dissociated into hydrogen and carbon, these elements recombining during the cooling according to a definite law which produced a whole crude containing all the normal constituents.

The experiments of Bergius on which the present hydrogenation processes are based have further proved this mutability of the constituents of hydrocarbon masses at high temperatures and pressures, and have demonstrated that the addition of free hydrogen to the dissociated elements results in the production of liquids containing a larger proportion of hydrogen than was present in the original material.

Petroleum disseminated in minute quantity through deeply buried strata and not yet collected into accumulations of sufficient magnitude to be determined by the drill may be repeatedly subjected, by subsidence or otherwise, to relatively high temperatures and pressures for periods of time which, as compared with artificial cracking processes, are almost infinite. Thus, the physical changes caused by dissociation which may occur in a petroleum after it is once formed may be indefinitely great in their extent and entirely indefinite as to their nature. In other words, it is perfectly safe to assume that unless a petroleum, after its formation, is maintained under nearly constant conditions as regards temperature and pressure, its proportions of gaseous, liquid, and solid constituents and the proportionate relation between the aliphatic, unsaturated, naphthenic, and aromatic constituents may be profoundly and repeatedly modified.

At temperatures lower than those required to dissociate and wholly rearrange the elements of an oil, fractional distillation might be an important factor in modifying the characteristics of an oil. If we assume the possibility of oil-containing rocks being gradually heated from one side, as during subsidence, the rise in temperature might be so slow as to produce simple distillation of the crude, vaporizing first the lighter, then the heavier fractions, and destroying any bituminous constituents. If these fractions, which would be continuously produced at certain constant-temperature levels through which the rocks were moving, should chance to fall into different migration paths, they would be permanently separated and we should have the material for two or more accumulations differing from each other and from the original crude in their properties.

In addition to changes due to dissociation and to fractionation with varying temperature and pressure, other physical changes may take place during the migration of an oil through strata of porous clays, shales, and other rocks having no chemical action on hydrocarbon constituents of the petroleum. The use of filtering clays in the purification of gasoline and lubricating oils is well known. In the ordinary use of these materials they are so applied as to adsorb and retain various impurities existing in prepared fractions, such impurities being mainly of a bituminous nature. As used commercially, these clays must be applied to the oil in relatively minute quantities and for extremely brief periods; consequently, their action is limited to such a degree as to make it seem very superficial. Further, these clays are applied in a substantially dry condition and do not function when water-soaked, from which it seems that the bodies of such materials through which petroleum might migrate, and which would almost certainly be water-saturated, would be little if at all effective in modifying the characteristics of the oil.

This last objection is readily overcome. The destruction of the effectiveness of a clay by water-soaking is caused solely by the filling of the pores with water, by which the entry of oil into these pores is prevented, the clay being applied in the form of separated grains suspended in the oil mass. If the conditions are reversed and the clay is retained in a dense mass through which the oil is forced, the water may readily be displaced from the pores of the clay and the oil be brought into effective contact with the mineral. Furthermore, migrating oils would be in contact with the mineral during very long periods; thus, many clays and shales which, in the limited time available for a laboratory test, would show no modifying action whatever, might produce an effect greater than we can obtain artificially with the most effective selected clays.

The percolation of a mixture of hydrocarbons of different molecular weights through a mass of porous and chemically inert material results in the adsorption and retention of the bodies having the highest molecular weight, those of lower molecular weight passing through. If the quantity of adsorbent material available is sufficient only to retain the heaviest bituminous bodies, the sole effect on the oil would be to reduce the depth of its color. The occurrence in places of a deposit of light-colored or white oil is unquestionably caused by the migration of darker-colored oils through beds of adsorbent material, the accumulation consisting solely of the first oil to pass through the adsorbent. As migration through the adsorbent strata progresses, bodies of progressively higher molecular

weight are released by the adsorbent and pass on to intermix with the more volatile and lighter-colored fractions already accumulated. When such selective adsorption has reached its limit by the long continued passage of a crude through a limited body of solid material, the accumulation at the farther side of this body would consist of a substantially whole oil, deprived only of the heaviest fractions of the bitumen. The adsorbent would then be nearly free from liquid and, if encountered in drilling, would appear merely as a blackened shale.

The effects of the migration of oil through porous strata are: to reduce the depth of coloration of the oil by the removal of bituminous constituents; to produce an incidental removal of the heavier oxygen and sulphur compounds; and to increase the relative proportion of the more volatile elements. The extent of the change in each of these respects depends on the distance travelled, on the character of the rocks through which the oil migrates, and on the stage at which the migration is interrupted. If it stops at the point where only the first fractions have passed through the adsorbent bodies into the reservoir in which the oil is finally found, the product may be a highly volatile light-colored oil containing a large amount of gas; but if the migration continues to the point where the adsorbent strata becomes completely choked with the heaviest fractions, the change in composition would probably not be observable either to the eye or by analysis.

Crude oils may be variously classified. Commercially, oils are distinguished mainly by relative weight or so-called gravity, which approximately indicates the volume relation between low-boiling and high-boiling constituents. Except for comparing oils of the same chemical characteristics, gravity is a very unreliable index to the proportion of the more volatile elements, being strongly influenced by the structure of the principal hydrocarbon groups and by the presence of such incidental constituents as bitumen.

Chemically, oils may be classified according to the preponderating group of hydrocarbons. Thus, the crudes of Pennsylvania consist of the lighter fractions almost exclusively of members of the aliphatic or paraffine series. Russian oils consist mainly, and many California oils to a less extent, of members of the naphthenic group. Several California crudes contain, in considerable proportion, members of the aromatic or benzene group, which is an important constituent of low-temperature coal-tar and the larger part of high-temperature tar. The lighter olefins are too unstable to exist in quantity in natural petroleum, but are the chief constituent of the products of liquid-phase cracking. These group

classifications, which are rarely made, are actually very important, as the susceptibility of an oil to artificial cracking, the knock rating of the straight-run gasoline, and the working characteristics of the lubricants depend almost entirely on the nature of the preponderating groups of hydrocarbons.

Finally, oils have been classified by the presence in notable quantity of some entirely incidental constituent, as sulphur or bitumen, from which we have the "sulphurous" oils of West Texas and the "asphaltic" oils of California and the Gulf Coast. Such classifications reflect mainly on the selection of refining methods and in that respect may be of some importance.

The profound and far-reaching effect which free sulphur may exercise on a petroleum during either its formation or its subsequent migration and storage has seemingly not been recognized. Sulphur in the free or elementary form is widely present in the earth's crust and particularly in such sediments as have been formed by the erosion of eruptive rocks or have been subjected to the infiltration of waters arising in volcanic formations. The sulphur which would be effective in this connection would not be that collected into beds or lenses, such as are found in Texas and Louisiana, these probably being too dense and impervious to be brought into contact with any large amount of oil. But in the arid region of recent volcanic activity lying east of the Sierra Nevada, large areas of clay and shale contain free sulphur in proportions varying from a trace to 20 per cent or more, this sulphur being completely and evenly disseminated through the mass of sediment, and this same condition is believed to exist in many regions in which petroleum is found or through which it has migrated. A minute trace of this element, which would escape observation in any ordinary analysis, would suffice to produce all the results about to be described. It is important in this connection that sulphur is freely soluble in cold oil and thus may be picked up at any stage in a migration and become effective at a later stage of higher temperature.

At a slightly elevated temperature, beginning at about 300° F., free sulphur readily oxidizes petroleum, particularly the higher-boiling part, forming bituminous bodies soluble in the oil. The type of oxidation here referred to does not involve the addition of oxygen, but rather the subtraction of hydrogen, a small part of the sulphur probably combining with hydrocarbons to form sulphur alcohols and esters, the larger part evolving as hydrogen sulphide.

This compound is a gas, soluble in petroleum and miscible with petroleum gases, readily soluble in water, and very unstable. It readily gives up its hydrogen to such oxidizing agents as metallic oxides or to atmospheric oxygen dissolved in water, and under the influence of slight temperature changes may dissociate into free hydrogen and free sulphur which do not readily recombine. In the first case the sulphur only, in the second both the sulphur and the hydrogen, are set free to combine with more oil under suitable conditions. The sulphur, at least, and sometimes the hydrogen also, may act on the oil repeatedly, the latter only at such temperatures as may cause dissociation of the hydrocarbons, but the former at constant temperature and at a temperature but little above that actually observed in the deeper wells in California.

The effect of the continued action of free sulphur on a migrating oil would be the gradual conversion of its heavier liquid fractions into bitumens. If the migration path were through rocks having the adsorptive power already mentioned, the bitumens would tend to concentrate and to be retained in these rocks and under such circumstances the proportion of light ends in the oil would be increased by the removal of part of the heavier fractions. This effect would be produced at constant temperature and might readily be carried to such a point as to account for the complete removal of high-boiling constituents and the accumulation of reservoirs of very volatile oil. On the contrary, if the migration did not involve adsorption and removal of the bitumens thus formed, they would accumulate in the oil and in the final reservoir, thus accounting for the numerous crudes which contain notable quantities of bitumens along with normal proportions of high- and low-boiling liquids.

If the migration were under such conditions that the mass of oil and gas was raised to the temperature of dissociation, any hydrogen set free by the breaking down of hydrogen sulphide would affect the carbon-hydrogen ratio of the mass and result in an increased proportion of more volatile constituents or of aliphatic hydrocarbons.

Certain other influences, which as a rule are obvious, may modify the characteristics of petroleum. Thus, the bitumen content may be increased by direct oxidation, with the addition of oxygen, on contact of the crude with atmospheric oxygen dissolved in percolating waters or with strata containing iron and other oxides. This action is in evidence on the surface, around seepages of oils originally containing almost no bitumen, which oxidize to tars or to solid brea. Purified lubricating oils diffused in a layer of granulated lead and exposed to air and sunlight may thus be converted into solid asphalt in a few hours, with actual increase

of weight, the lead acting as an oxygen carrier. The bitumen produced by addition of oxygen differs somewhat from that caused by the removal of hydrogen.

Evaporation of lighter constituents from shallow beds causes the production of "dead" oils, which contain only such gas as is in solution at the pressure caused by hydraulic head, and its effects are too well known to need comment.

Finally, contact of petroleum with either acid or alkaline waters and with oxidizing agents may increase or diminish the content of such chemically reactive constituents as petroleum acids, phenols, and the various known compounds of sulphur and nitrogen. Such effects are complicated, obscure, and of little importance.

CONCLUSION

Briefly stated, the foregoing theory necessitates a presupposition of the production of petroleum by destructive distillation of organic matter, animal or vegetable, with the probability that it is so produced in extremely minute quantities at any one time and place. It implies such destructive distillation at relatively very low temperatures, perhaps as low as 300° or even 250° F., at which temperatures the tendency would be toward the formation of a maximum yield of hydrocarbons of low boiling point and high hydrogen content. It indicates the probability that most petroleums, as originally formed, are of more or less uniform nature, made up of entire series of hydrocarbons ranging from the lightest to the heaviest, the structure of these groups and to a less extent the preponderance of light or of heavy ends being to some extent controlled by the hydrogen-carbon ratio of the raw material. It involves the possibility that petroleums already formed and perhaps already greatly modified may be subjected to temperature and pressure changes sufficient to dissociate and reconstitute the crude, with further changes in its characteristics, and the certainty that temperature changes of less magnitude may modify the oil by fractional distillation. It indicates the manner in which migration through porous strata may modify a crude in the direction of increasing the proportion of lighter and more volatile hydrocarbons, the manner in which contact with sulphur may increase the proportion of bituminous constituents, and the manner in which the second named modification followed by the first named may still further increase the proportion of light ends.

In condensing such a subject within the limits of a paper to be read, it is hardly possible to attempt proof of the statements made or to illus-

trate by examples, many of which are available. This the writer hopes to do in a paper of greater length, though whether anything useful would be accomplished by so doing is uncertain. Seemingly the conclusion reached is entirely negative, in that neither the location nor the present characteristics of a petroleum are, with any certainty, indicative either of its original properties or of the place or time of its origin.

GEOLOGICAL NOTES

HOCKLEY SALT SHAFT, HARRIS COUNTY, TEXAS

The Houston Salt Company is sinking a shaft for the mining of salt in the north-central part of the Hockley salt dome,[1] near the northeast corner of the Coghill Survey, northwestern Harris County, Texas. This operation is of particular interest, not only because the porous water-bearing calcite and limestone zone at the top of the cap series has been successfully passed through and the shaft is now perfectly dry, but also because of the opportunity it has offered to study, at first hand, the cap-rock section and the cap-rock-salt contact (Fig. 1), and because of the data which strongly suggest a sedimentary origin for the anhydrite.

The calcite or limestone part of the cap is brecciated and interwoven with veins of calcite and flecked with calcite vugs, many of which hold oil. Minor amounts of barite and strontianite occur ordinarily as concretions. At the base of the limestone is a steel-gray calcitic sand 15-30 inches thick. This sand is in sharp contact with the smooth, slightly polished upper surface of the gypsum. The gypsum is 18 feet thick and grades into the anhydrite through a vertical distance of 3 feet. The gypsum-anhydrite contact dips northward 4½ feet in the 15-foot width of the shaft. (See shaft section, Fig. 4.)

The anhydrite section is characterized by many joint systems. Horizontal, or almost horizontal, joints are pronounced. The horizontal planes are smooth with slickensides and a fine coating of pyrite gives a dark, almost black color to the surface. Jointing systems at various angles, approximating 45°, are common but not predominant. These planes are unpolished or poorly polished. At many places several parallel horizontal, or almost horizontal, planes continue around the shaft, simulating the appearance of sedimentary beds. Other joint planes ranging up to vertical also occur.

At a depth of 800 feet several fragments of anhydrite were found coated with a green copper mineral. Pyrite commonly occurs in the anhydrite as dark thin films or strata as much as ¼-inch thick. At, and an inch or two above, the anhydrite-salt contact a dark reddish brown iron oxide compound persists almost around the perimeter of the shaft.

[1]Alexander Deussen and Laura Lee Lane, "Hockley Salt Dome, Harris County, Texas," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 570.

FIG. 1.—Contact between overlying anhydrite and salt in Hockley shaft at depth of 1,011 feet.

ANALYSIS OF ANHYDRITE
Depth, 350 Feet

	Per Cent
Calcined gypsum	24.5
Anhydrite	69.41
Excess SO_3 (combined)	2.78
Sodium chloride	.19
Ferric oxide and alumina	.37
Silica and insoluble	2.30
Calcium carbonate	.45

The most significant fact suggesting sedimentary origin of the anhydrite is the presence, at depths between 800 and 900 feet, of horizontal stratified bands of gray, calcareous sandstone in the anhydrite ranging from a fraction of an inch to an inch in thickness (Fig. 2). The horizontality of the bands (Fig. 2) is attested by the fact that the fragment also shows a bore hole, that was drilled vertically, at right angles to these bands. Sandstone inclusions as large as 4 inches in diameter, of yellowish gray, grayish green, or faintly reddish sandstone, also are common between depths of 800 and 900 feet (Fig. 3). These inclusions are either

FIG. 2.—Horizontal bands (light) of sandstone in anhydrite (dark), showing part of vertical bore-hole.

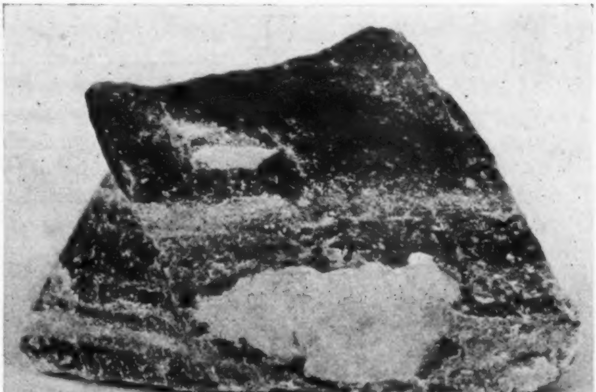

FIG. 3.—Included sandstone fragments (light) and sandstone bands in anhydrite.

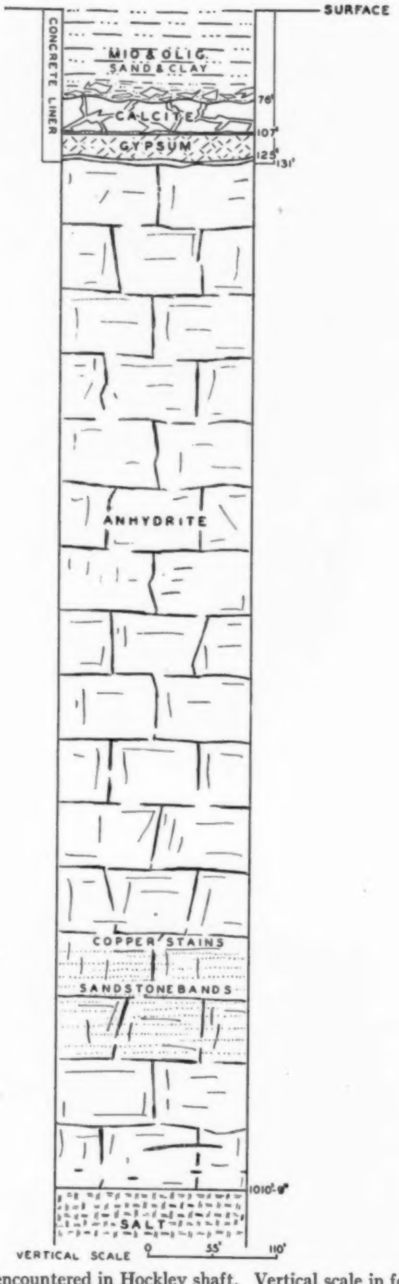

FIG. 4.—Section encountered in Hockley shaft. Vertical scale in feet and inches. Miocene and Oligocene sand and clay at top.

isolated masses, or are distributed along the sandstone bands, ordinarily with their longer axes parallel with the stratification.

A horizontal lens of salt, 10 feet long, 5 feet wide, and about 10 inches thick, was encountered at a depth of 973 feet. This salt was in sharp contact with the surrounding anhydrite and seemed to have no connection with any other body of salt. When dissolved, a sample left no residue, indicating its purity. A few smaller salt lenses were noticed between 973 feet and 1,010 feet, 9 inches, the top of the main salt.

The main anhydrite-salt contact is sharp and practically horizontal on all four walls of the shaft (Fig. 1).

INSOLUBLE CONTENT OF SALT BELOW MAIN CONTACT

	Per Cent Insoluble
1 inch below anhydrite contact	11.26
1 foot below anhydrite contact	6.46
6 feet below anhydrite contact	5.55

The included areas of lighter and darker tone in the wall shown in Figure 1 indicate shadows or textural features in the salt and anhydrite, rather than inclusions of one in the other. The whole appearance of the contact proves a sudden sharp transition from anhydrite above to salt below.

L. P. TEAS

HOUSTON, TEXAS
February 16, 1931

DRILLING FOR GEOPHYSICAL DATA IN YELLOWSTONE NATIONAL PARK

Two wells have been drilled in Yellowstone National Park under the direction of the Geophysical Laboratory of the Carnegie Institution of Washington for scientific purposes. Approximate figures have been made available by A. L. Day, director of the Geophysical Laboratory. The first well, drilled in 1929 back of Old Faithful Hotel, penetrated 20 feet of silica sinter, 200 feet of glacial drift filled with sinter, and 200 feet of altered rhyolite. The steam had a pressure of 60 pounds per square inch at the bottom. In the second well, drilled in 1930 in the Norris Geyser basin, altered rhyolite was found from the surface to the total depth, 260 feet, and the steam at this point had a pressure of 300 pounds per square inch.

SIDNEY POWERS

TULSA, OKLAHOMA
March 5, 1931

YEAGER CLAY, SOUTH TEXAS[1]

Overlying the Fayette sandstone in south Texas are massive or obscurely bedded clays in pastel shades of green, gray, yellow, or pink, containing little or no sand and ash. These clays, because of the rarity of the outcrops and the absence of organic remains, have not received the attention they deserve. Deussen[2] included them in the Frio clay. Dumble[3] probably included them in the upper part of his "Whitsett beds," the lower part of which form the upper part of the Fayette sandstone of the present writers. Bailey,[4] in most of the sections, assigned them to his Frio, which was not the Frio of Dumble, 1894.[5] Unfortunately Dumble's original description includes only outcrops of the volcanic series and, for that reason, the name Frio must, by the accepted laws of nomenclature, be retained for that series. For the lithologic unit of dominantly non-volcanic clays, persisting from northern Live Oak County to the border, and several hundred feet in maximum thickness, the name *Yeager* is proposed, from the Yeager Ranch on the Cotulla-San Diego road in northeastern Webb County. The clays are exposed, at intervals, from a distance of approximately ¼-½ mile east, to 3½ miles southeast, of the ranch house, where they are succeeded by the dominantly volcanic Frio formation. Fossil wood is commonly associated with the Yeager, but no other organic remains, either macro- or microscopic, have been recovered from exposures or from well cores. The age has not been established. The absence of any evidence of unconformity between the Fayette and the Yeager is suggestive of Jackson age, but this appearance of conformity may be due to the non-resistant lithologic character of the two formations rather than to continuous deposition, and the field, and possibly organic, evidence may later prove the Yeager to be of Oligocene age.

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IOWA CITY, IOWA
March 23, 1931

[1]Published by permission of the acting director, U. S. Geological Survey.

[2]Alexander Deussen, "Geology of the Coastal Plain of Texas West of Brazos River," *U. S. Geol. Survey Prof. Paper 126* (1924), pp. 91-95.

[3]E. T. Dumble, "A Revision of the Texas Tertiary Section with Special Reference to the Oil-Well Geology of the Coast Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 4 (July-August, 1924), pp. 432-35.

[4]Thomas L. Bailey, "The Gueydan, a New Middle Tertiary Formation from Southwestern Coastal Plain of Texas," *Univ. Texas Bull. 2645* (1926), pp. 42-52.

[5]E. T. Dumble, *Jour. Geol.* Vol. 2 (1894), pp. 554-55.

DISCUSSION

PENNSYLVANIAN OVERLAP

A. I. Levorsen's excellent paper entitled "Pennsylvanian Overlap in the United States," which appeared in a recent issue of this *Bulletin*,[1] represents such an elaborate discussion of a difficult problem that criticism of some of the details may seem picayune. Because of its very thoroughness, however, statements made in his paper will probably be accepted as fact, whereas Levorsen himself says not only "that all of the material comes from outside sources and that responsible references are available for the facts described," but that he "has been forced to take sides on many controversial questions."[2] The writer of this note agrees in general with Levorsen so far as his conclusions are concerned, but wishes to point out that had *other* "responsible references" been chosen, some of the "facts" on which his conclusions were based would be somewhat markedly different from those he actually employed.

In the correlation chart given in Figure 7, page 124, for example, a somewhat long erosional interval is indicated between the deposition of the Pitkin and Winslow formations of northern (northeastern?) Arkansas. But, as a matter of fact, there is not a single known locality in Arkansas at which the Winslow rests directly on the Pitkin limestone. The initial Pennsylvanian sediments everywhere in northern Arkansas belong to some part of the Morrow group, not to the Winslow formation, though it is true that east of the Harrison Quadrangle the late Chester and early Pennsylvanian sediments have not yet been accurately subdivided. However, the Pitkin at some places in northern Arkansas *has* been removed by pre-Pennsylvanian erosion; at those places the Morrow, not the Winslow, rests disconformably on some part of the Fayetteville. In northeastern Oklahoma, however, the Morrow locally *is* missing, and in such places the Winslow rests on the Fayetteville or older Mississippian formations.

In Figure 10, page 129, the correlation chart for northern Arkansas (I assume that Mr. Levorsen means *northwestern* Arkansas) correctly depicts the Morrow resting disconformably on the Pitkin. But the hiatus is portrayed as representing most of Chester and all of early and mid-Pottsville time. It is true that there is a disconformity between the Pitkin and the lower Morrow sediments[3] at most places at or near the northernmost extent of those formations in Arkansas; and, as stated before, it is also true that locally all of the Pitkin has been eroded. But a few miles farther south the Pitkin and Hale (oldest Morrow) formations are, so far as one can ascertain, perfectly conformable.

[1]A. I. Levorsen, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 2 (February, 1931), pp. 113-48.

[2]*Op. cit.*, pp. 114 and 142.

[3]See Plate 17B, *Arkansas Geol. Survey Bull. 3* (1930).

This approximate, if not complete, conformity is further indicated, as will be explained later, by the residual Mississippian element in the Morrow fauna, and by the late Chester aspect of the Pitkin and upper Fayetteville faunas. Stated in another way, therefore, the objection is not that there has been no Pennsylvanian overlap in northern Arkansas but in that area and especially in northeastern Oklahoma there is good evidence for the progressive northward transgression of the early Pennsylvanian seas, but rather that the Morrow is indicated in the correlation as much too young and the Pitkin as much too old.

Closely linked with the foregoing comments is the criticism of the disposition, on the same correlation chart, of the Jackfork, Stanley, Atoka, Caney, and Wapanucka formations. The writer is loath to add further words to a controversy, still far from settled, which in its various ramifications involves more than a dozen Carboniferous formations and a similar number of well known geologists. He does wish to reiterate, however, that other "responsible references" indicate that the Jackfork, as well as the Stanley, is a Mississippian, not a Pennsylvanian formation. Some of the reasons for such a disposition of the Jackfork are briefly summarized in the following paragraphs.

Any correlation of late Mississippian and early Pennsylvanian rocks in Arkansas and Oklahoma is embarrassed by the fact that the Caney seems to overlie the Jackfork sandstone, and it in turn the Stanley shale, the last two comprising approximately 13,000 feet of essentially unfossiliferous clastic sediments considered by some geologists to be Pennsylvanian in age. The lower Caney, however, contains an exceptional black shale faunal assemblage, here designated as the "Caneyella fauna," which is found also in the definitely Mississippian Moorefield and lower Fayetteville formations of northern Arkansas. But these Arkansas beds are overlain by the Wedington sandstone and upper Fayetteville shale (which contain faunas younger than the "Caneyella" type), by the still younger Pitkin limestone, and finally by the Morrow. The fauna of the latter, although somewhat definitely Pennsylvanian, contains a conspicuous residual Mississippian element as well as a pronounced proemial Pennsylvanian assemblage. The very early Pennsylvanian age of the older Morrow sediments, that is, the Hale sandstone, the lower Bloyd shale, and the Brentwood limestone lentil, therefore, rests on a firm paleontologic basis.

It is also interesting to notice that the paleobotanic evidence, which commonly is at variance with the evidence of the invertebrates, particularly in regard to important boundaries, is here corroborative. The flora of the shales associated with the Baldwin coal (which occurs in the Bloyd shale between the Brentwood and Kessler limestones) is regarded by David White as of late middle or early late Pottsville age. Thus, the several hundred feet of fossiliferous Morrow sediments which are *below* the Baldwin coal, and which at some places rest conformably on the Chester, must be early or mid-Pottsville or both. This very early Pennsylvanian age of most, if not all, of the Morrow beds is further emphasized if one remembers that the paleobotanical evidence commonly indicates greater youth for any particular set of strata than does the evidence afforded by the invertebrates.

To complete the story and further complicate matters, the "Caneyella" beds of the Caney are overlain by essentially barren shales which are followed by the typical Wapanucka limestone, or at least by beds carrying a Wapanucka-

Morrow fauna. This same fauna occurs elsewhere at the boundary between the Jackfork and Atoka formations, now commonly regarded as at the base of the Atoka. But, in order to appreciate the significance of these facts, it should be pointed out that the "Winslow" formation of northern Arkansas minus the Hartshorne sandstone at its top is the exact equivalent of the Atoka minus the beds with a Morrow fauna at its base. Thus, the key to the situation lies in northern Arkansas, where the fossiliferous character of the beds and the simplicity of the structure make the Mississippian-Pennsylvanian boundary reasonably definite. For just as there can be no reasonable doubt as to the Mississippian age of the sediments subjacent to those which in northern Arkansas contain a Morrow fauna, so should there be (in the opinion of the writer and several others) little hesitation in placing the Jackfork beds, which occur below beds with the Morrow-Wapanucka fauna, also in the Mississippian. It is, of course, recognized that most of these sediments thicken toward the south, but to place the entire 6,000-7,000 feet of Jackfork sediments in the Pennsylvanian, regardless of the fact that they are clearly overlain by beds with the very early Pennsylvanian Morrow-Wapanucka fauna, seems entirely unreasonable. Finally, there is no reason for placing the Atoka as the equivalent of the upper part of the Jackfork. The Atoka at all places known to the writer rests on the Jackfork, though locally the boundary is ascertained with some difficulty.

If, therefore, one grants the Mississippian age of the Jackfork formations, Figure 11, on page 131, would have to be considerably altered. In addition, the maximum thickness of the Pottsville, as shown in Figure 17, would be reduced to approximately 10,000 feet in Arkansas (the Atoka has a maximum thickness of at least 9,400 feet in Perry County), and the maximum thickness of the Mississippian shown on Figure 18 would be increased to approximately 13,000 feet in the Ouachita area. Neither of these alterations, important as they are, would radically change the general aspect or significance of either of the maps.

In conclusion, I agree with Levorsen's contention that a much larger proportion of the early Pennsylvanian sediments was derived from the broad central arch of the continent than has hitherto been thought. In order to make this important point, however, Levorsen has perhaps unconsciously minimized the significance of those very areas which his isopachous maps indicate were most important as sources of supply of early Pennsylvanian sediments. In other words, one can find no fault with the statement that "the expanding Pennsylvanian sea. . . . was contaminated by material derived from relatively local uplifts and sources such as the Wichita-Arbuckle Mountains in Oklahoma" and "the Cincinnati and Nashville domes in Ohio, Kentucky, and Tennessee," but the designation of Appalachia and Llanoria as "other relatively local disturbances" will probably not meet with universal approval.

Carey Croneis

Department of Geology
University of Chicago
February 24, 1931

ON THE DISGRACE OF USEFUL SCIENCE

The psychological reactions of the human race are essentially fixed, having been established before the dawn of history. Their modification in Recent time has been too small to be of record. One interesting trait of human nature is the inferior status, other things being equal, assigned to useful work. The basic reaction is seemingly related to a sense of power—a feeling of superiority of those served over those who serve. However this may be, to depreciate the useful and assign strange virtue to the idly ornamental is a trait fixed deep in human nature.

The useful is the Cinderella of the scientific household. Honor and a scientific degree may be obtained by writing a thesis on the amorphous structure of a Cambrian jelly fish, or the theoretical coefficient for temperature in Orion. But should a worker in science spend a lifetime devising means for the human race to be warmer, better fed, transported, or housed, he is beneath scientific notice. He will work alone, discouraged and ignored during the years when one gesture of appreciation would mean much to him. When he is old, gray, and dying; when honors mean little; when a people he has served acclaim him, and the hum of ten thousand dynamos and glow of ten billion lights can no longer be shut out by thick and bolted doors; then—when our honors are merely idle gestures—we confer our empty degrees.

And it is all so upside down. Pure science can exist only by means of a far-flung line of scientific outcasts in office, factory, and field, who build the laboratories and instruments with which pure science works. It is supported by the generosity of patrons who have worked weary years at useful science, by the donations of their children, and by taxation of the useful.

The human trait mentioned is very real. Only the other day I read a statement by some ornamental scientist to the effect that petroleum geologists should be ashamed of their nefarious, shameful, or dishonest profession; the exact words escape me. I wonder if this scientist uses an automobile? rides on western railroad trains? has seen the United States battle fleet strung out in line? the screen of black smoke laid down by circling destroyers? Surely, he sends his suits to the cleaner. These things are all in league with a nefarious, shameful, or dishonest profession.

I speak partly against my inclination. Strange as it may seem, I, a despised petroleum geologist, would rather read an article on the amorphous nature of a Cambrian jelly fish, than one on a great oil field. I continually neglect my scanty business to write papers on ornamental geology. I, too, have that universal failing of human nature. But it will not save me in the eyes of the keepers of virtue, for this is my thesis: Why depreciate science—anything—because it is useful? Why honor any callow youth who can stay awake in class, and depreciate the work of men who labor a lifetime and make humanity happier?

The disrepute of useful science is nowhere better illustrated than by the idea that those engaged in it necessarily have the intelligence of mental defectives or of children. Some years ago a famous non-economic scientist for whom I have the highest regard contributed an article to the bulletin of my economic association. The article was a class-room lecture fitted to under-

graduates and was written in haste, without the scientist taking the trouble to append a single footnote or proof on the many doubtful assertions made. There were other articles in that issue by comparatively unknown economic workers, and each shone like a star beside that of the famous scientist. The good and kindly man had, of course, no idea of the insult he conveyed. He had written down to his equals.

It would be unfair to imply that all workers in pure science consider themselves the sole guardians of truth, for this is not the fact. The truly great among them are the salt of the earth. The great mingle with the crowd with no thought of contamination; it is the lesser man who needs protest his virtue. Science is truth; and truth is in the busy street, as well as on the mountain top.

Let none of us who work at useful science delude himself. We are the ugly ducklings, the grimy furnace men. Our task is to keep humanity warm, well, and happy.

Let our tribulations teach us compassion for all things,—yea, even for the amorphous jelly fish of Cambrian time. Should it ever be found that he has been a source of oil—that he has in any slight degree been useful to humanity—he will stand defiled. Pure science will disown him, and his name will never more be spoken except in whispers, with averted eyes. In such a crisis let there be no hesitation, but let us take this poor, amorphous outcast to our bosoms. His offence will have been the same as ours: *we serve*.

J. E. Eaton

Los Angeles, California
March 4, 1931

"CRETACEOUS LIMESTONE AS A PETROLEUM SOURCE ROCK IN NORTHWESTERN VENEZUELA."[1] REPLY TO DISCUSSION BY R. A. LIDDLE

I am interested to notice that Mr. Liddle's observations have led him, also, to consider the La Luna limestone as a petroleum source rock, and that he finds evidence suggesting that the oil in the Cogollo limestone "has migrated into the formation along lines of breaking." There are a few points in his discussion concerning which I wish to comment.

1. The Colon shale carries a benthonic foraminiferal fauna of Upper Cretaceous age which is clearly distinct from the pelagic foraminiferal fauna of the La Luna formation.

2. I think the ellipsoidal and discoidal bodies in the La Luna limestone to which I have made reference may be properly called concretions. Although they range from a few inches to many feet in diameter and generally show no particular internal structure, they are certainly distinct segregations within the main limestone mass and were clearly formed after the deposition of the inclosing rock (Fig. 1). It is of interest to note that while locally these con-

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 3 (March, 1931), pp. 229-46.

cretions are fossiliferous, the writer has cracked scores of them in certain areas without finding a trace of megascopic fossils.

3. I do not understand Mr. Liddle's reference to "an absence of calcite" noted by me in the La Luna limestone. The many foraminiferal tests of this rock are largely preserved as clear crystalline calcite and obviously both the Cogollo and La Luna limestones contain much calcite. That of the Cogollo, however, is generally more coarsely crystalline than that of the La Luna.

FIG. 1.—Typical La Luna limestone near Villa Isabel, Santander, Colombia. Notice bending of strata both above and below the discoidal concretions which are everywhere characteristic of this formation.

4. I have referred to the original La Luna sediment as a *Globigerina* ooze. This it must clearly have been, judging from the percentage of tests of *Globigerina* and other pelagic foraminifers in the consolidated rock. However, I did not wish to imply that the sediment necessarily accumulated in the ocean depths with which present day *Globigerina* oozes are commonly associated.

On the contrary, I am inclined to believe in an origin in waters of moderate depth, although I think it entirely possible that the La Luna was formed in deeper water than the Cogollo.

5. Possibly I have given an erroneous impression as to the profusion of megascopic fossils in the La Luna formation. It is certainly true that mollusk remains are locally common. However, in most of the river sections which I have studied in the northern part of the District of Perijá, large fossils are very rare or absent in this formation.

6. Although Mr. Liddle's discussion of my paper is concerned principally with the La Luna formation of the northern part of the District of Perijá, State of Zulia, it should be noticed that the same formation in essentially similar development is known in Colombia (the Villeta formation) and in Eastern Venezuela (the Guayuta formation). The distinctive character of the rock is thus not the product of any particular local environment, but is the result of conditions of deposition which must have prevailed during a part of the Cretaceous throughout much of northern South America and possibly neighboring regions for a sufficient length of time to permit the deposition of from 500 to 3,000 feet of limestone.

HOLLIS D. HEDBERG

VENEZUELA GULF OIL COMPANY
MARACAIBO, VENEZUELA
March, 1931

REVIEWS AND NEW PUBLICATIONS

"The Dolomites of the Stillwater, Wellington, Garber, Hennessy, and Duncan Formations. By C. A. MERRITT and J. W. MINTON. *Okla. Acad. Sci.*, Vol. 10 (November, 1930), pp. 69-72. 4 microphotographs, 3 photographs.

A brief account of high percentages of dolomite in the lower Permian is given. This is of particular interest, because a high dolomite content in these otherwise clastic rocks has hitherto been generally unsuspected.

More than a hundred samples were collected from widely separated places in several counties. Regardless of the high percentage, the distribution of the dolomite is erratic. This percentage varies considerably, both laterally and vertically, in short distances.

The most common type of dolomite is that occurring in the pseudo-conglomerates or "mudstones." A tentative hypothesis is advanced to explain the origin of these beds in which they are considered to be the result of bedded dolomite deposition (some containing detrital quartz), with subsequent wave action breaking and rounding fragments of the dolomite. The fine material was deposited between the coarser pebbles as cement. Weathering results in the conglomeratic appearance, although the beds are not conglomerates in the true sense of the word. The lack of orientation of fine parallel laminations, suggesting bedding planes, in the pebbles is evidence of rolling. This would destroy the parallelism of the bedding planes. The cross-bedded character of many of the dolomite ledges is clear evidence of their having been subjected to wave action.

In emphasizing the great quantity of dolomite in these sediments the authors tentatively estimate that the volume of at least 5 per cent by weight of these formations considered as a whole is dolomite.

Wave action is considered the sole cause for uneven distribution of strata and formation of the shale conglomerates. The reviewer considers the lack of sorting and sudden lateral gradation to be caused chiefly by potential and shifting currents. The high complexity of the ripple-mark forms (linguoid, et cetera) seems to be the result more of current than of oscillatory wave action.

The source of the dolomite remains at present an open question.

HENRY SCHWEER

NORMAN, OKLAHOMA
February 10, 1931

International Geological Congress, Compte Rendu, 15th Session (South Africa, 1929), Vol. II (1930).

"A Brief Review of the Dwyka Glaciation of South Africa," by ALEX I. DU TOIT. Pp. 90-102.

This paper deals with widespread glacial conditions in the southern part of the African continent during late Paleozoic time.

An interesting comparison of glacial conditions in the Argentine of simultaneous age is given. Faunal evidences suggest that glaciation had commenced by early Pennsylvanian time and quite probably, as indicated by plants, before the close of Mississippian time. This is of great significance in its bearing on our "probable" glaciation during the Caney time in the Ouachitas of southeastern Oklahoma.

Comparison of the boulders found in this area shows that they have a history similar to that of those found in South Africa, Argentina, and Australia.

"Notes on the Investigation of the Spore Content in Certain Karroo Rocks." By H. HAMSHAW THOMAS. P. 222.

This interesting article discusses the discovery of convenient methods for the separation of spores. Thin slips of dark shale were placed in hydrofluoric acid and were found to give a dark organic residue. After being washed and concentrated with a centrifuge, many winged microspores were found.

For investigation of the spore content of coal seams the author recommends that the coal be cut into small blocks of approximately 5 mm. square, and these placed in warm saturated aqueous caustic potash for two or three weeks. The blocks may then be washed and treated with a solution of potassium chlorate in strong nitric acid for a day or two. On being transferred to a dilute alkaline solution, the coaly material dissolves, leaving a residue of spore coats, fragments of cuticle, et cetera. After this material is washed and concentrated, it can be examined under the microscope.

"Die Entstehung des Erdöles, verwandter Kohlenwasserstoffe und gewisser Kohle." By P. KRUSCH. Pp. 291-98.

In this paper dealing with the genesis of petroleum the author proposes to subdivide the methods of origin into organic and mineralogic as opposed to the generally accepted terms of organic and inorganic, because the term mineralogic indicates a more divergent origin than the term inorganic. Both organic and inorganic origins are concerned with hydrocarbons which in chemistry are regarded as organic. In contrast to this, "mineralogic origin" expresses more exactly the chemical union of metallic carbides and oxides with ground water to form petroleum.

The origin of oil is regarded as comprising two important factors, primary and secondary. The oil found at shallow depths is regarded as secondary, that is, because of the earth temperature, the oil is distilled and forced to the shallow horizons, although the primary horizons are deep-seated. This interpretation is based on observation of shallow fields where wells are from 1,000 to 1,600 feet apart. One produced several thousand barrels and others produced very little. The difference in the production of the wells is considered to be caused by the migration from deeper horizons to the upper through larger and smaller channels. Wells drilled within the main channels can produce great quantities.

The conclusions of the foregoing paragraph are entirely contrary to our observation in the United States, as well as in Mexico and South America.

Oil in shallow sand, variable in volume, moves in accordance with the variation in porosity in the oil sands, rather than in accordance with its proximity to a hypothetical channel from deeper sources.

"L'origine del petrolio." By T. SACCO. Pp. 299-301.

In Italy, petroliferous horizons are almost unfossiliferous. The regions richest in hydrocarbons are connected with plutonic type formations, with manifestations of volcanic activity, with beds of sulphur, the origin of which is more or less endogen, and with tectonically much troubled, fractured, or diapyric regions. Therefore, observations made deduce a genetic connection between hydrocarbons and endogenic (plutonic, volcanic, and sulphurous) manifestations, the latter being of deep origin, undoubtedly inorganic.

"Sulla natura e genesi biogenica della pelagosite." By E. ONORATO. Pp. 315-19.

This article gives an excellent description of microscopical and chemical research on the nature and biochemical origin of pelagosite. It concludes that pelagosite (sea-weed) is a conglomeration of aragonite with very impure fibrillous crystals caused by inorganic salts and sea-weed decomposition with partial fibro-radiated concentric structure of biochemical origin. The organic origin is determined from the action of a calciferous sea-weed of the Chrococcus species and with the help of other calciferous weeds as evidenced by the difference of structure. The biochemical origin is proved by the presence of small quantities of strontium.

BRUCE H. HARLTON

TULSA, OKLAHOMA
March, 1931

RECENT PUBLICATIONS

AFRICA

"Résultats des récentes prospections de pétrole en Afrique équatoriale francaise," by J. Jung. *Annales de L'Office National des Combustibles Liquides*, No. 4 (July-August, 1930), pp. 615-34, 5 photographs, 2 maps.

GENERAL

International Petroleum Technology, Vol. 8, No. 3 (February, 1931). Successor to *Oil Field Engineering*, lately *Oil*, as now published monthly by National Petroleum Publishing Company (Cleveland, Ohio), to supplement *National Petroleum News*, not to supplant it.

"Oil Migration Theory Challenged," by Frank R. Clark. *International Petroleum Technology*, Vol. 8, No. 3 (Cleveland, Ohio, February, 1931), pp. 18-22. 4 illus.

"Possibilities of Oil Mining in Appalachian Fields," by Paul D. Torrey. *International Petroleum Technology*, Vol. 8, No. 3 (Cleveland, Ohio, February, 1931), pp. 28-34. 10 illus.

"Bibliography of North American Geology, 1919-1928," *U. S. Geol. Survey Bull. 823* (1931). 1,000+ pp. (Supt. Documents, Washington, D. C.) Price, $1.25.

Physiography of Western United States, by Nevin M. Fenneman. (McGraw-Hill Book Company, Inc., New York, N. Y., 1931.) 534 pp., 173 figs., 1 pl. Green cloth. Approximately 6 × 9 inches. Price, $5.00.

Field Geology, by Frederic H. Lahee. Third edition, revised and enlarged. (McGraw-Hill Book Company, New York, N. Y., 1931.) 789 pp., 539 illus. Price, $5.00.

GEOPHYSICS

"Some Observations on Geophysics," by Ronald K. DeFord. *International Petroleum Technology*, Vol. 8, No. 3 (Cleveland, Ohio, February, 1931), pp. 46-52. 2 illus.

GERMANY

"Das Erdöl im Wiener Becken." *Petroleum Zeits.* (Berlin, February 4, 1931), pp. 91-105. A group of papers on petroleum in the Vienna basin presented before the International Drilling Association in Vienna, December 8, 1930, including brief papers on "Subsurface Conditions," by Karl Friedl; "Geology of Czecho-Slovakian Oil Fields," by L. Sommermeiir; and "New Oil District near Brünn," by E. Schnabel.

TEXAS

"Survey of the Underground Waters of Texas," *U. S. Geol. Survey Press Notice 50678* (February 16, 1931). 31 mimeographed pp., 4 maps. Coöperative report by U. S. Geol. Survey and Texas State Board of Water Engineers.

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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SUGGESTIONS TO AUTHORS

In submitting reviews of foreign articles on areal geology, for the department "Reviews" in the *Bulletin*, authors are requested, whenever possible, to furnish

a copy of the most appropriate map published in the original article, so that our readers may more easily understand the significance of the facts disclosed. Such a map should be provided with title and symbols in English, and should be sufficiently described in the text to make it useful.

Attention has been called by one of our members to carelessness, too often observed in articles submitted for publication by the Association, in the use of the terms "high-gravity oils" and "low-gravity oils," and in failure to designate whether specific gravity, or Baumé gravity, or A. P. I. gravity, is meant. This criticism is wholly justified.

We urge all contributors to acquire the habit of using the terms, "light oils" and "heavy oils," instead of "low-gravity oils" and "high-gravity oils," also always to designate the kind of gravity referred to, either in a footnote, or by a definite statement in the text, or by the proper abbreviations (Sp. Gr., Bé., or A. P. I.), immediately following cited figures for gravity.

F. H. Lahee

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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

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The Association maintains an employment service at headquarters under the supervision of the business manager.

This service is available to members who desire new positions and to companies and others who desire Association members as employees. All requests and information are handled confidentially and gratuitously.

To make this service of maximum value it is essential that members coöperate fully with headquarters, especially concerning positions available to active and associate members.

JAMES C. TEMPLETON, managing director of the International Geophysical Prospecting Company, Ltd., addressed the Oil Industries Club, London, February 4, on the subject, "Geophysical Prospecting for Oil and Gas." The address is reported in *The Petroleum Times* (London) of February 7, pp. 175-76.

FREDERICK G. CLAPP, consulting geologist, 50 Church Street, New York, read a paper at a recent symposium of the Institution of Petroleum Technologists on salt domes. Mr. Clapp's paper is summarized in *The Petroleum Times* (London) of February 7, pp. 199-201, under the title, "Salt Domes of Texas and Louisiana Gulf Coast."

CHARLES N. GOULD, director of the Oklahoma Geological Survey, Norman, has a brief article on "Geophysical Exploration for Oil Contrasted with Doodle Bug Idea" in the *Oil and Gas Journal* for February 19.

E. CALL BROWN, formerly with the California Petroleum Corporation, is geologist for the McKeon Oil Company of Los Angeles, California.

E. H. WELLS, president of the New Mexico School of Mines at Socorro, is state geologist of New Mexico, succeeding C. G. STALEY, now proration umpire in the Hobbs district.

M. H. STEIG, who was geologist for the Mexican Gulf Oil Company at Tampico, Mexico, has been with the Houston Oil Company since June, 1930. He has been located at Beeville, Texas, until recently, when he was transferred to the Houston office, where he has charge of the subsurface department. His mailing address is Box 1779, Houston, Tex.

E. J. LONGYEAR COMPANY, mining engineers, Foshay Tower, Minneapolis, Minnesota, have issued a well illustrated book of 101 pages, in boards, their catalog No. 8, "Longyear Diamond Core Drills and Supplies."

MORRIS M. LEIGHTON, state geologist of Illinois, is president, and GEORGE C. BRANNER, state geologist of Arkansas, is secretary, of the Association of American State Geologists.

DAVID WHITE, principal geologist of the U. S. Geological Survey, lectured at Yale University in February and March on "The Geology of Coals."

EDGAR A. KEELER, formerly district geologist of the Sinclair Oil and Gas Company at Abilene, has been transferred to Amarillo, Texas, to be in charge of the Panhandle district.

M. C. ISRAELSKY is micropaleontologist for the Union Gas Corporation, in Houston, Texas.

C. M. DORCHESTER, of the Gulf Refining Company at Shreveport, Louisiana, has been transferred to the land department of the company.

J. W. KISLING, JR., of the Amerada Petroleum Corporation, has been transferred from Roswell, New Mexico, to Tyler, Texas.

A. R. MORNHINVEG is micropaleontologist for the United Gas and Fuel Company, at Shreveport, Louisiana.

J. S. YOUNG represents the United Gas Corporation at Jackson, Mississippi.

Northwestern University, Evanston, Illinois, offered special lectures on applied geology in March. During the first two weeks, W. E. WRATHER, consulting geologist of Dallas, Texas, lectured on the geology of petroleum; the third week, KIRK BRYAN, professor of the department of geology of Harvard University, lectured on the geology of engineering problems; and the last week, SHERWIN F. KELLY, consulting geologist and geophysicist of New York City, lectured on geophysical methods.

CHARLES F. BASSETT and GLADYS HAWLEY BASSETT announce the birth of their son, NEAL FAVOR, on January 20, 1931, in Maracaibo, Venezuela. Mr. and Mrs. Bassett are with the Lago Petroleum Corporation.

I. R. SHELDON has moved from Wichita Falls to 311 Milam Building, San Antonio, Texas.

CORBIN D. FLETCHER and HENRY N. TOLER, geologists recently with the Gulf Refining Company, with field headquarters at Meridian, Mississippi, have opened consulting offices at Jackson, Mississippi, for work in the Gulf Coastal Plain. Mr. Fletcher's address is 1203 Pinehurst, Jackson, Mississippi.

The program of the Dallas Petroleum Geologists, in their meeting of March 7, 1931, was a discussion covering the producing sands on the east rim of the East Texas basin. The program included the following papers: "Paleontology of the Tokio Formation," by MERLE C. ISRAELSKY, United Gas Corporation, Houston, and N. L. THOMAS, Pure Oil Company, Fort Worth; "Source of Woodbine-Tokio Sand Series," by GAYLE SCOTT, of Texas Christian University, Fort Worth, and W. C. SPOONER, Box 1195, Shreveport; "Age of the Sands Below the Browntown Marl," by E. M. RICE, Box 308, Grand Saline, Texas,

and H. V. Howe, Department of Geology, Louisiana State University, Baton Rouge, Louisiana; "The Use of Heavy Minerals in Sand Determination," by W. B. Moore, Dallas; and "East Texas-Louisiana Cross Sections," by F. B. Plummer, Bureau of Economic Geology, University of Texas, and W. C. Spooner.

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